DIRECT SHEAR TESTING OF MARINE SEDIMENT

By

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United States
Naval Postgraduate School

THESIS

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Lieutenant Commander, United States Navy
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ABSTRACT

Traditionally, the methods used to determine the mechanical properties of marine sediments were those used in the field of soil mechanics. These methods are generally acceptable when the sediment tested is plastic or at water contents below the liquid limit. However, for predicting in-situ conditions, that is for sediment at water contents above the liquid limit, the problem is complex.

Specifically, the determination of shear strength of an unconsolidated-undrained sample by the direct shear method was found to exhibit an angle of internal friction ranging from 19 degrees to 23.5 degrees. This indicates that the shear strength of the sediments is dependent on the normal load applied to it.

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I. INTRODUCTION

A. BACKGROUND

There has been an effort in recent years to determine the physical properties of the ocean floor. This interest has been generated by private industry, particularly that of the petroleum field and also by varied groups within the United States Government. This interest has resulted in a better understanding of the ocean floor.

Since the petroleum industry became interested in offshore oil deposits they have begun to more fully investigate the nature of the bottom. One of the factors in the successful exploitation of offshore oil deposits is an understanding of the mechanical properties of marine sediments. What effect a certain type platform will have on the bottom, or how a particular sediment will react to drilling, are but two of the problems associated with sediment strength.

Various agencies of the United States Government have been showing an increased interest in the ocean. The Man-in-the-Sea project, DSSP, and any one of a number of deep submersible development projects point this out. The role of the GLOMAR CHALLENGER in investigation of deep marine sediments is but one step in this direction.

Problems that are associated with deep submersibles, in an investigation of bottom, are penetration, breakout, and trafficability. It is of the greatest importance to know as fully as possible what the strength properties of marine sediments are. There is a great variation in strength characteristics both from sediment to sediment and within a given type depending on how it was deposited [Earth Manual 1960].

[illegible]

An example of how little is understood of the ocean floor, or the deep ocean itself, was the inability to locate, much less salvage, the lost submarines THRESHER and SCORPION. It was not known whether or not THRESHER would be visible or would have sunk into the bottom. The determination of an answer to this apparently simple question was an important step toward a better understanding of the ocean floor.

All these problems, trafficability, penetration, breakout, and general sediment behavior are, directly or indirectly, associated with sediment shear strength.

B. NATURE OF THE PROBLEM

For years, shear strength testing of soil samples of a terrestrial origin has been carried out. Municipal building codes generally require this test, while the Bureau of Public Roads has recommended that tests be carried out in all highway construction [American Society for Testing and Materials 1964]. Thus, the testing procedure and results are fairly well defined. This is, however, not the case with marine sediments.

Many of the samples of marine sediments to be tested have water contents above the liquid limit, that is, are assumed to behave as a liquid. However, a true liquid in the fluid mechanics sense, has no shear strength. This is not the case with marine sediments. Consequently, fluid theory cannot explain the presence of shear strength. Any one of three methods may be used to measure strength: the triaxial test, the unconfined compression test, or the direct shear test. Each method has its individual merits and its advocates, but for testing of marine sediments none of these procedures can be considered ideal. This study is concerned with the direct shear method.

Terrestrial soils may be classified as either cohesive or non-cohesive, depending upon whether the individual soil particles have a predominant binding attraction for one another. In the case of marine sediments from deep ocean origins, samples are found to be chiefly of a cohesive nature. A cohesive sample above the liquid limit is extremely difficult to test.

Direct shear testing may be conducted in either of two modes, stress-controlled or strain-controlled. Stress-controlled tests are those in which the shear force is increased in such a manner that shear stress follows a predetermined pattern. Usually the objective is to increase the shear stress at a constant rate, although in some cases an incremental approach is used. The increments are applied nearly instantaneously and held until shearing strain ceases [Hough 1969]. Once failure occurs using the stress-controlled method, no further shear information can be gained about the sediment [Dawson 1949].

In strain-controlled tests the shearing force is applied such that shearing strain occurs in some specified pattern, i.e., the rate of strain is constant. The strain-controlled technique is the most common procedure used for it is felt to give the most conservative results [Hough 1969]. It should be noted that the rate of application of the shear force must not be too rapid or the strength value obtained may not be a true indication of the sediment's actual shear strength.

Once the method of control has been chosen the state of the sample must be determined. The sample may be tested in any one of three modes: drained, consolidated-undrained or unconsolidated-undrained. Consolidation of a sample is useful if an increase in shear strength is desired as noted by the Bureau of Yards and Docks [1967]. The latter,

unconsolidated-undrained, is felt to be nearest to the in-situ conditions of marine sediments [Earth Manual 1960], and for this reason was selected as the test mode on these studies.

To test in the unconsolidated-undrained mode the testing procedure must be carried out as rapidly as possible to prevent any unwanted drainage of pore water. The entire experimental set-up must be prepared before the sample itself is readied.

Sediment samples may be tested in either the undisturbed state, as extruded directly from the core linear, or in the remolded state. Remolding consists of thoroughly mixing of the sample before testing, thereby altering its natural in-situ condition. It has been observed that certain cohesive soil samples which in nature are quite firm, may become very soft when disturbed or remolded without change in water content. This effect is demonstrated in Figure 1. The test for shear strength of a marine sediment is the same for undisturbed or remolded samples in technique. For ease in handling, remolded samples were used in this work.

In order to conduct the direct shear test, a dead weight type normal load is customarily applied and is maintained constant throughout the test. In the case of marine sediments, the total weight of the solids in the overlying column is used. This normal loading and its variation during individual tests enables one to see if there is any variation of shear stress with normal load. Figures 2 and 3 show results expected from consolidated-drained samples and unconsolidated-undrained samples tested at various normal loads.

The slope of the plot on Figure 2 is an indication of the so called angle of internal friction, or Φ angle, expected in the case of unconsolidated-drained sample. In comparison, Figure 3 shows no such angle for the unconsolidated-undrained soil. This Φ angle is used as a measure of the resistance to shear of a sediment sample. The point where the line denoting the angle of internal friction crosses the shear stress axis is considered the cohesion of the sample under no-load conditions. Subsequent discussion of the angle of internal friction and cohesion will more fully explain their significance.

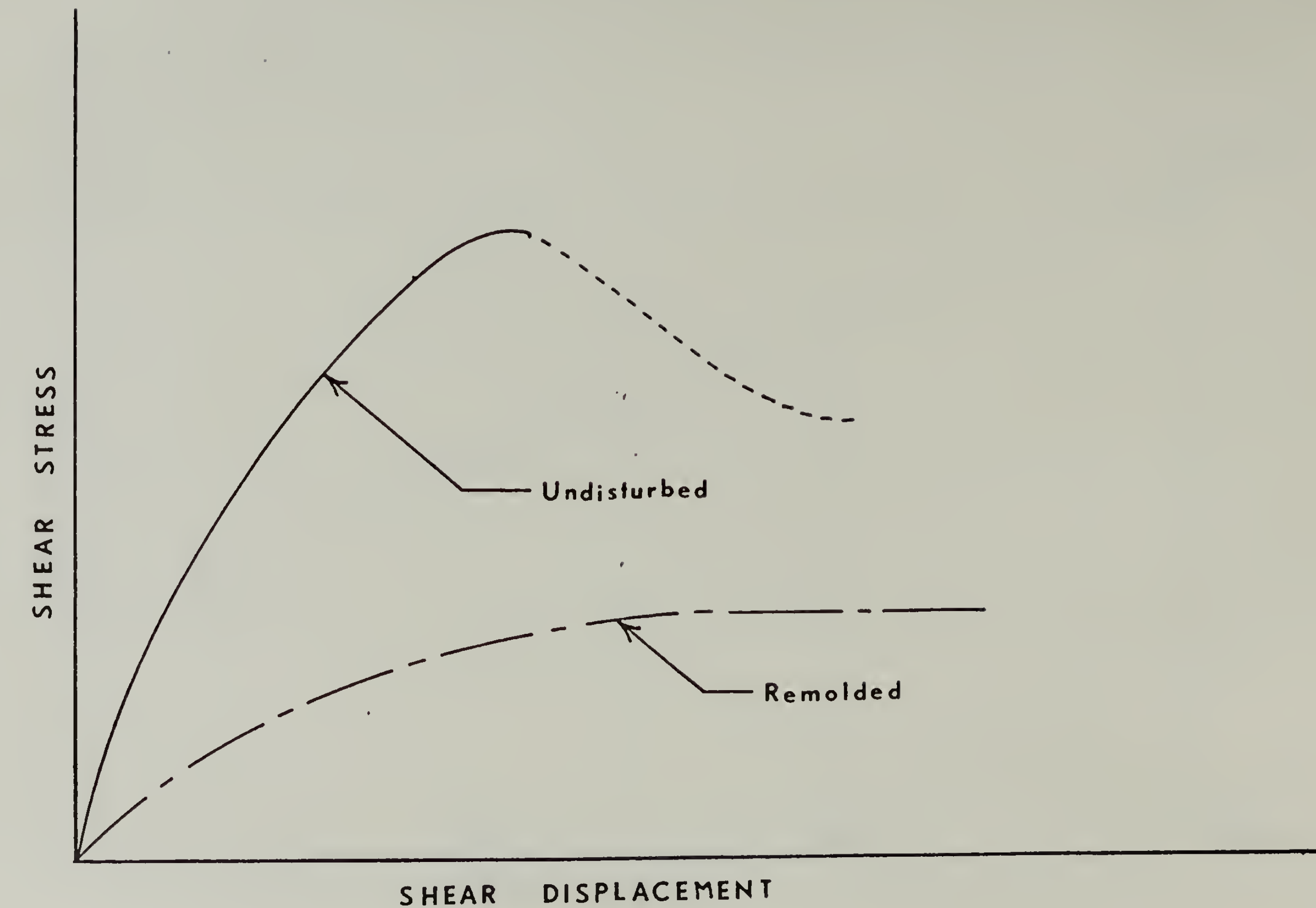


Figure 1. Typical Plot of Shear Force vs. Shear Displacement for Remolded and Undisturbed Samples

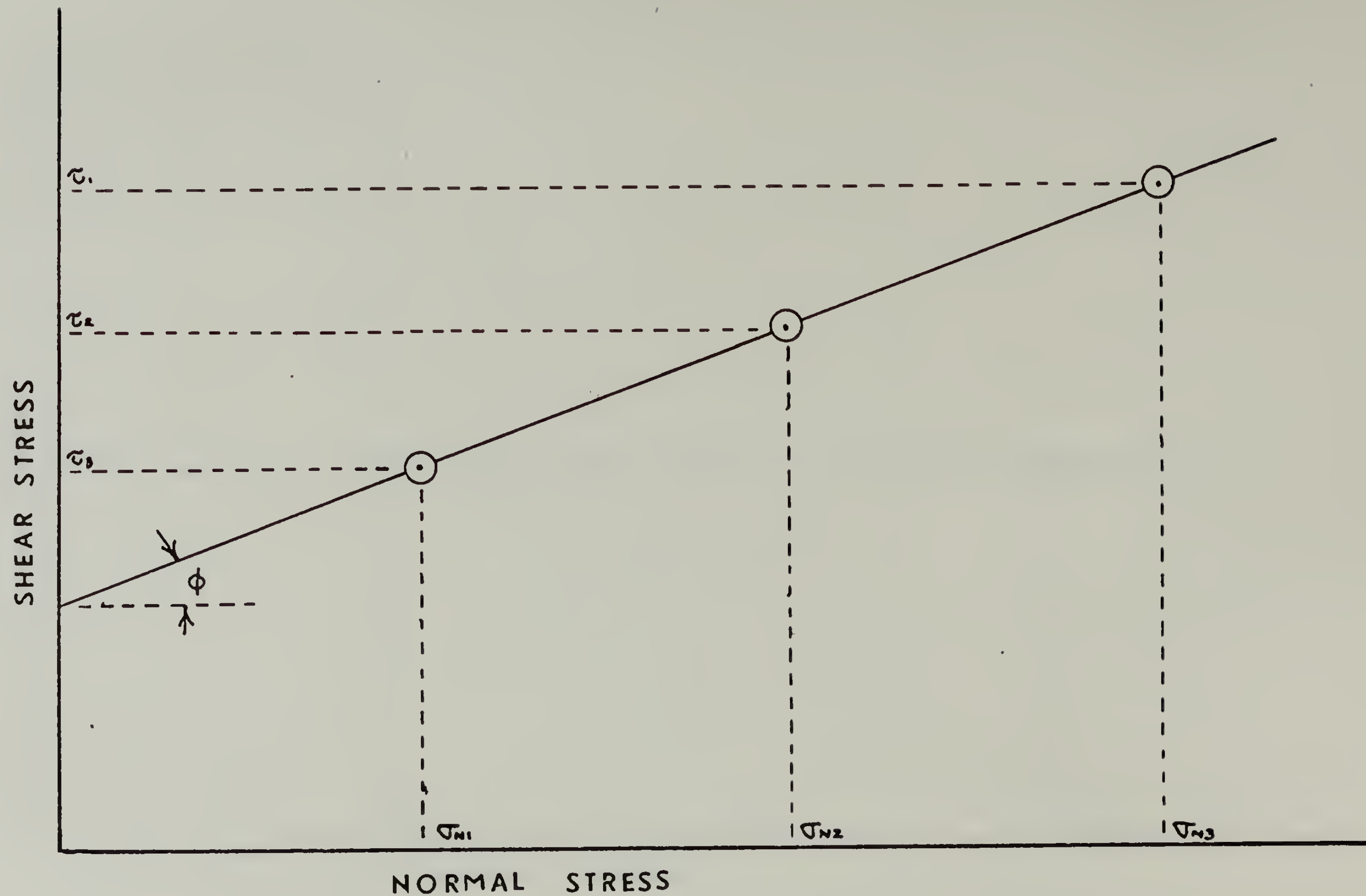


Figure 2. Plot of Shear Stress vs. Normal Stress for a Consolidated-Drained Sample

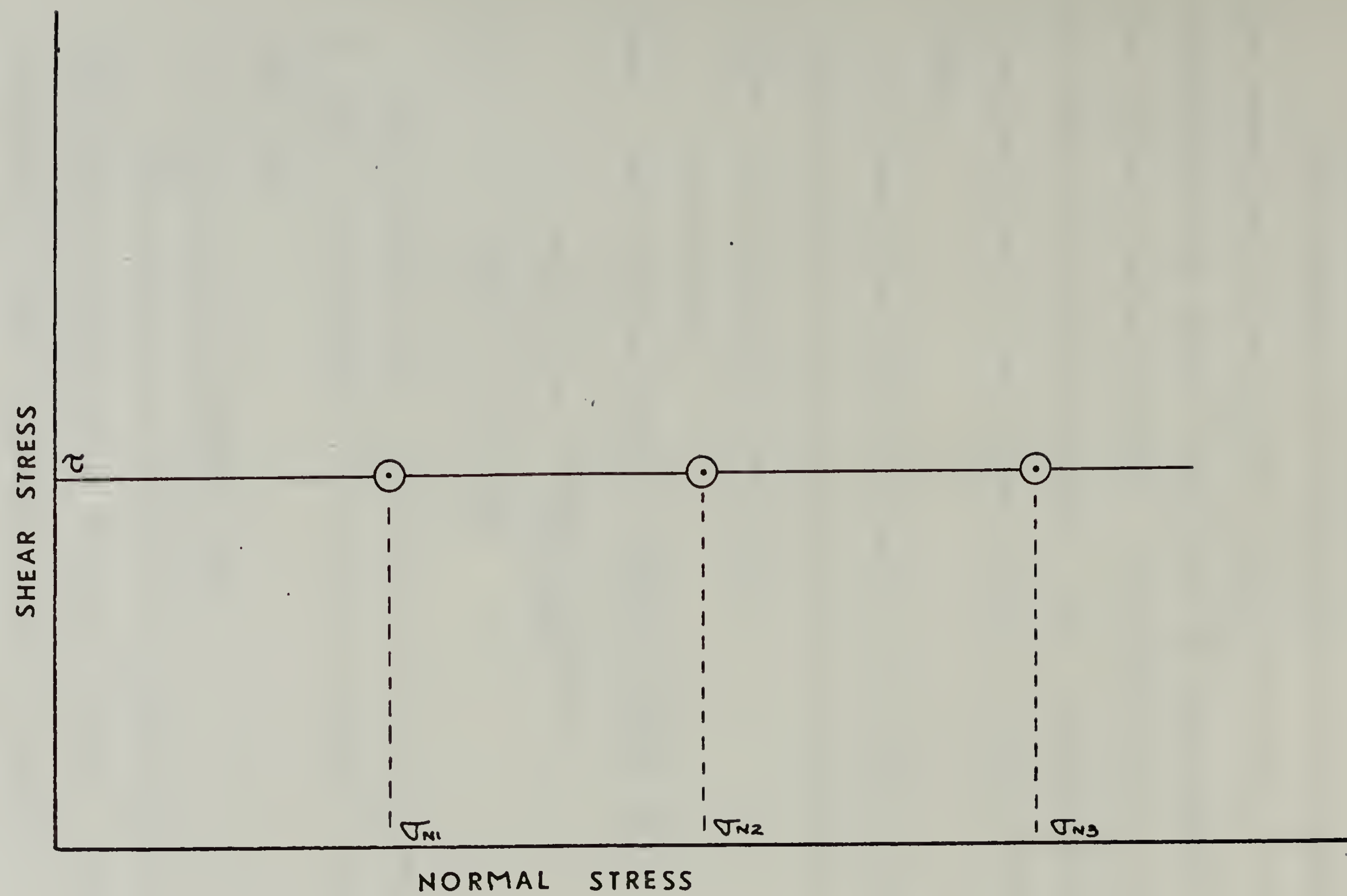


Figure 3. Assumed Shear Stress vs. Normal Stress for an Unconsolidated-Undrained Sample

C. GENERAL PROCEDURE

1. Determination of Normal Loads

It is necessary in the direct shear test to properly determine the normal loads to be applied. Such loads may vary in magnitude depending upon the desired results and the test apparatus in use. In the testing of marine sediments, determinations must be made of bulk wet density (BWD) and water content (WC). Standard laboratory procedures are followed to make these analyses, as are outlined by Lambe [1967].

The normal load utilized in testing these marine sediments is taken to be that of the weight of solids in the overlying sediment column. The calculation is as follows:

$$WS = BWD \times WC$$

where: $BWD = \text{Bulk wet density} = \dfrac{\text{weight of sample}}{\text{volume of sample}} \left(\dfrac{gm}{cc}\right),$

$$WC = \text{Water Content} = \frac{\text{weight of water}}{\text{dry weight}} \ (\%)$$

and $WS = \text{Weight of solids} \ \left(\dfrac{gm}{cc}\right)$

The normal load then is the product of the cross-sectional area of the sample, the thickness of the overlying sediment, and the weight of solids (WS).

2. Preparation of Sediment Sample

The sediment to be tested was thoroughly mixed and carefully worked into the testing device by spoon or spatula. Amounts are added incrementally in order to ensure no voids or trapped air pockets. When sediment samples are remolded the only considerations given are to density and moisture content, and no attempt is made to either control

or determine the structural arrangements of the particles. It is therefore necessary that the sample to be tested is kept as close as possible to its measured bulk wet density and water content prior to the beginning of testing.

3. The Shear Box and Speed of Test

The chief component of any direct shear apparatus is the shear box, for this is where the force is directly applied to the sample and where the normal load is generally applied. Figure 4 illustrates a typical shear box. Shear boxes are similar in most respects, variations usually consisting of the size and shape of the specimen and minor refinements of the gratings [Dawson 1949].

The base of the box generally is bolted or somehow affixed to the loading device, while the upper and lower parts of the box are held together by retaining screws which are removed immediately prior to the application of the shear force. In addition, the lower part of the box is usually attached to the stand by means of dowels. Top and bottom gratings are set above and below the sample to assist in holding the sample firmly to evenly distribute the normal load, and to prevent unnecessary loss of pore water. Solid bronze gratings are used for unconsolidated-undrained tests.

The size of the shear box varies considerably, but many laboratories have found the 3" x 3" or 4" x 4" box convenient [Dawson 1949, Lambe 1967]. A shear bos that takes a circular sample is convenient when tests are to be made from cores. In the case of remolded samples a box that takes either square or round samples is suitable. In general, the larger the individual soil particle of a sample, the larger the shear box should be in order to minimize the effects of side friction [Lambe 1967].

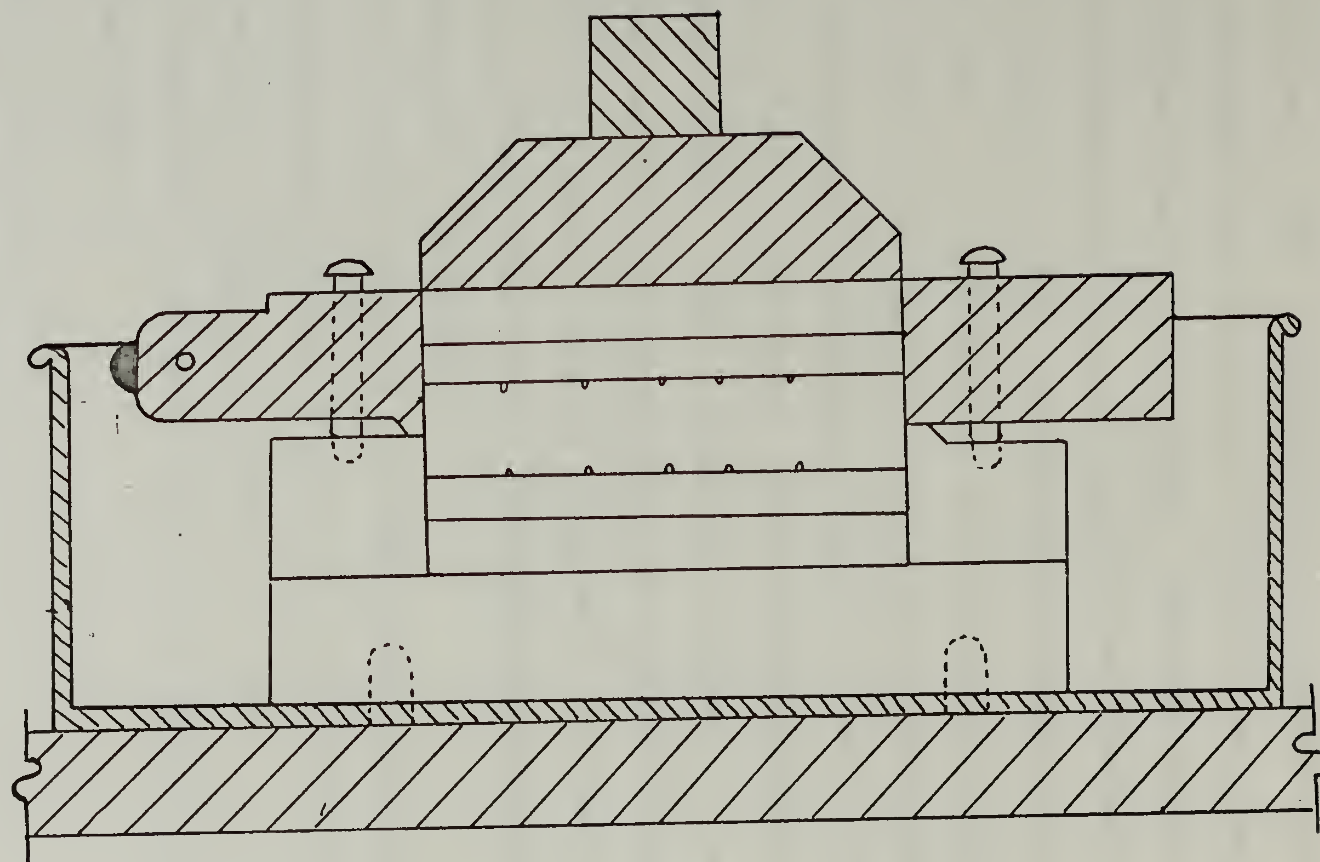


Figure 4. A Typical Shear Box

For an unconsolidated-undrained sample undergoing a strain-controlled direct shear test the shear force should be applied at a constant rate of about .02 in/min [Corps of Engineers 1951]. This rate may vary slightly from laboratory to laboratory, but usually results in no significant change in shear values. Regardless of the speed of advance selected, the entire test should be completed with a shear failure occuring in about three minutes or a maximum of five minutes [Dawson 1949]. It is recommended that the proving ring and displacement dial readings be made every 30 seconds until failure occurs.

When testing a remolded sample of marine sediment, or any cohesive sample, the shear stress will be found to build gradually until a maximum is reached. This is illustrated in Figure 5. Once this maximum has been reached and shear failure has occurred no more shear force is required to produce continued displacement. The shear force is calculated from the proving ring dial reading by multiplying by a conversion factor. For example:

with a ring factor equal to 5 lb/.0001 inches of displacement and a proving ring dial reading of .0003 inch at failure then,

$$\text{Shear Force} = 5\ \frac{\text{lb.}}{.0001\ \text{in.}} \times .0003\ \text{in.} = 15\ \text{lb.}$$

The shear stress, measured in lb/in^2, is calculated from,

$$\text{Shear stress} = \frac{S}{A}$$

where, S = shear force (lb.),

and A = area of shear plane (in.^{2}).

The shear strength developed by a marine sediment may be partially due to the cohesive nature of the sample and partially due to solid friction. Cohesive strength is frequently evaluated by means of either the vane shear or the unconfined compression tests. A suitable value

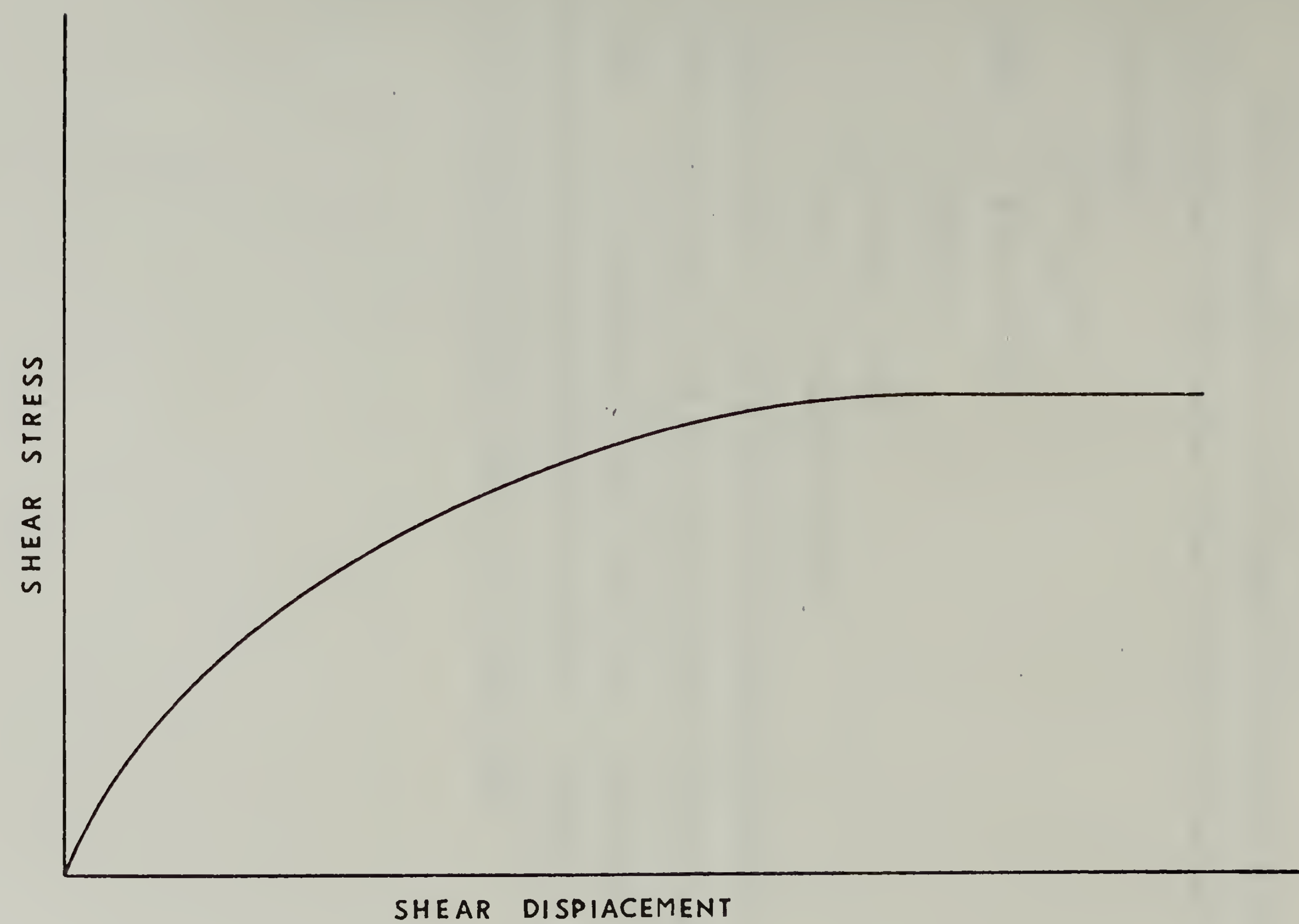


Figure 5. Typical Shear Stress vs. Shear Displacement Curve for Remolded Sample

may be obtained from a shear stress diagram at the point where the line of shear stress intercepts the shear stress axis (Figures 2 and 3). In addition, the slope of the shear strength curve is equal to the angle of internal friction of the material tested.

The two properties of unit cohesion and angle of internal friction can be related to the normal stress and the shear stress by Coulomb's Law, namely:

$$\tau = C + \sigma_N \tan \Phi$$

where, τ = shear stress,

C = cohesion,

σ_N = normal stress,

Φ = angle of internal friction.

From the above it is seen that if the sediment strength is independent of the normal load, with an angle of internal friction equal to zero, then $\tau = C$ or the shear strength would equal the cohesive strength of an unconsolidated-undrained marine sediment. Whether or not this might be the case was the prime objective of this study.

II. EXPERIMENTAL PROCEDURE

A. DESCRIPTION OF APPARATUS

The direct shear device utilized for this research was designed and build by Soiltest, Inc., of Chicago, Illinois, and modified by the Naval Civil Engineering Laboratory of Port Hueneme, California. It represents a strain-controlled direct shear device which, in its present configuration, is primarily utilized for the testing of unconsolidated-undrained samples. Figure 6 illustrates the device in its entirety.

1. Shear Box

The shear box pictured in Figure 7 is composed entirely of bronze. The upper and lower parts are designed to take a circular sample, as the majority of marine sediment samples are obtained with coring devices having circular cross sections. The diameter of the circular opening of the base (Figure 8) is 2.5 inches. Solid bronze gratings were used (Figure 9) to limit the escape of pore water from the sample during the test.

The base of the shear box is fixed to the frame of the shear device by four lugs, shown in Figure 10. The lower half of the block is permanently brazed to the base. The upper half is initially attached to the lower half by means of two dowels in one-eighth inch diameter holes drilled through the upper half and partially into the lower half of the shear box. Figure 11 shows these dowels in place. A monel brace designed as a bearing surface upon which the actual shear force is applied is attached to the upper half of the block. Figure 12 illustrates its appearance and function.

Figure 6. The Entire Direct Shear Testing Apparatus

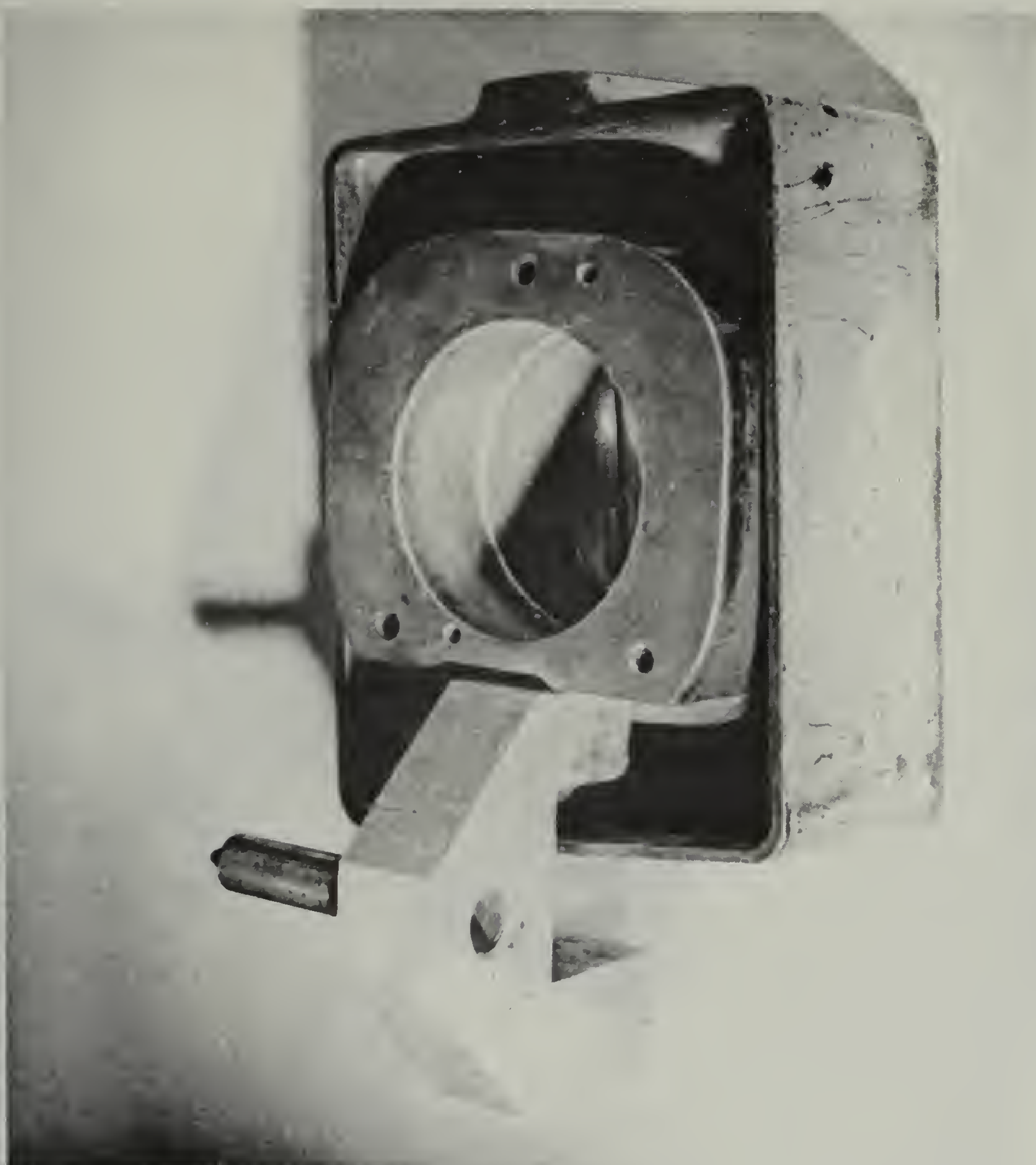


Figure 7. The Shear Box

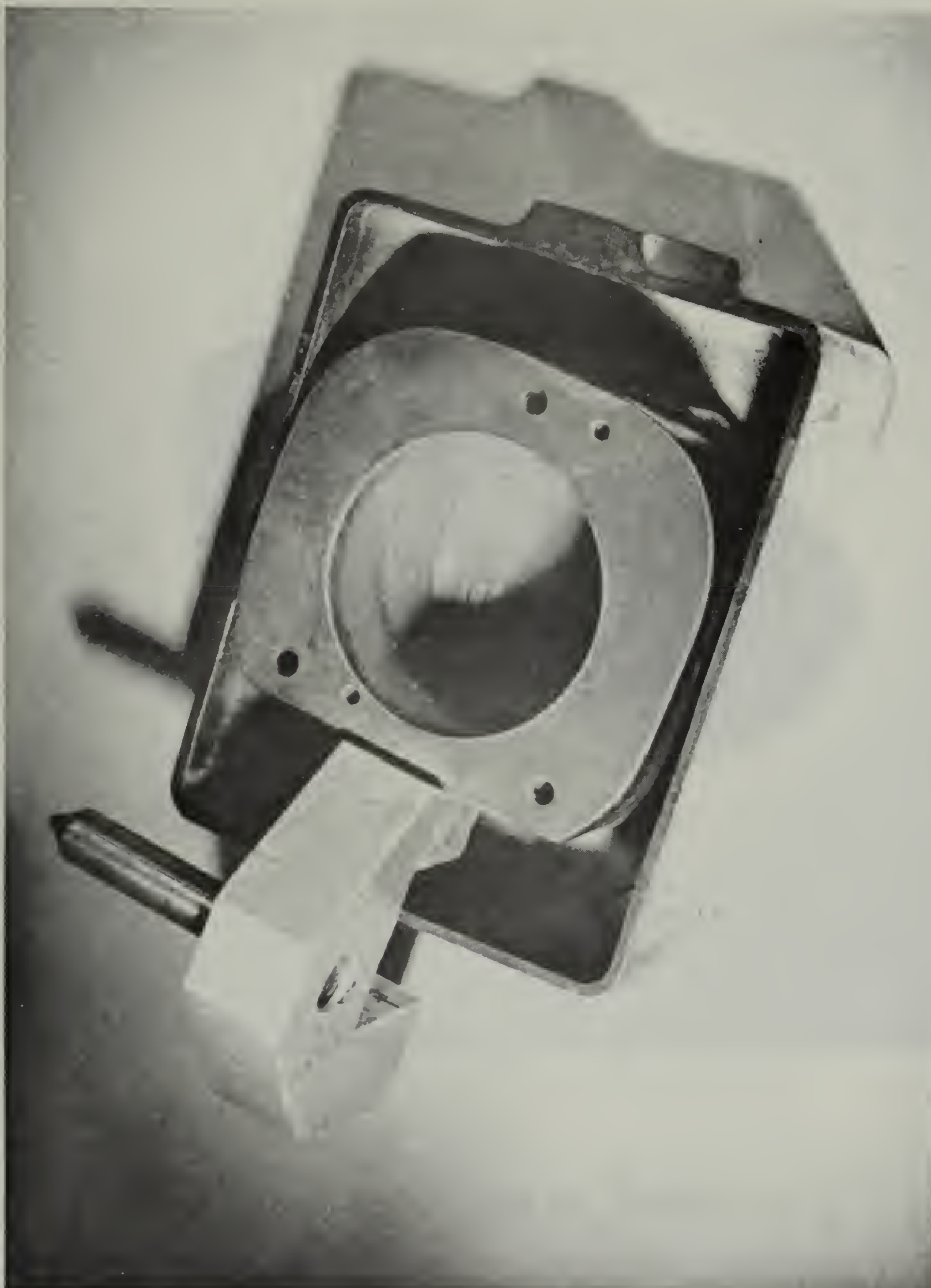


Figure 8. The Circular Well of the Shear Box

Figure 9. The Shear Box Gratings

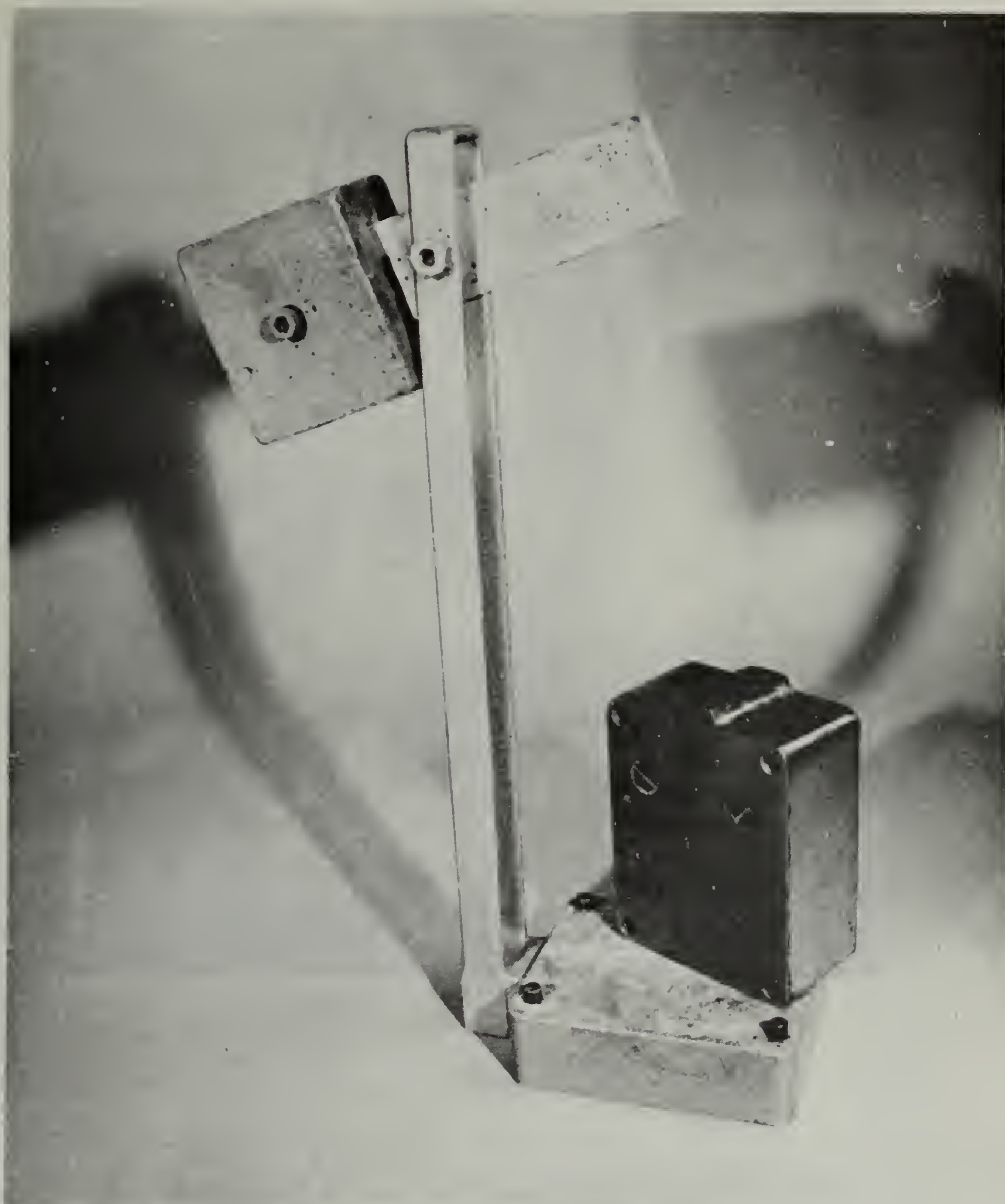


Figure 10. The Lug Assembly of Frame and Base of Shear Box

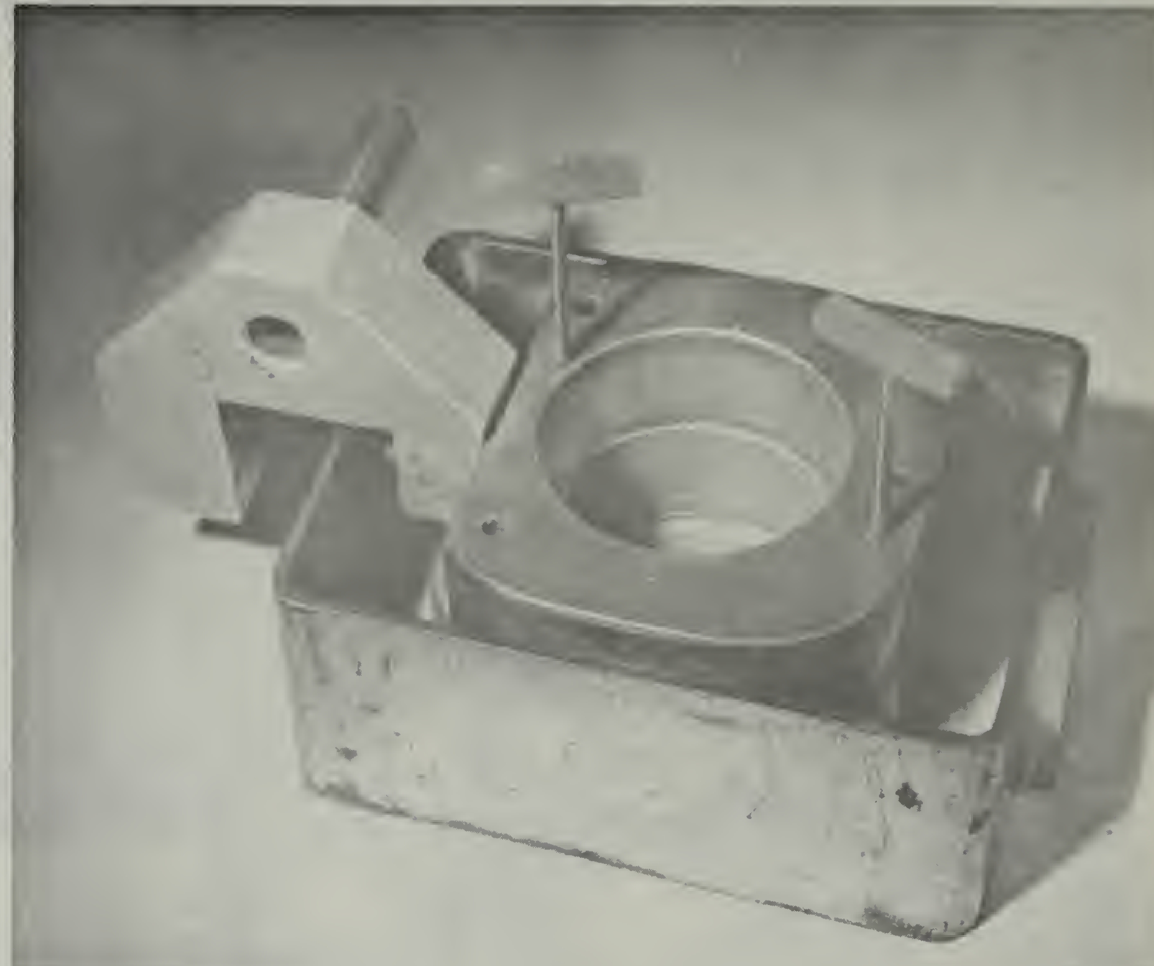
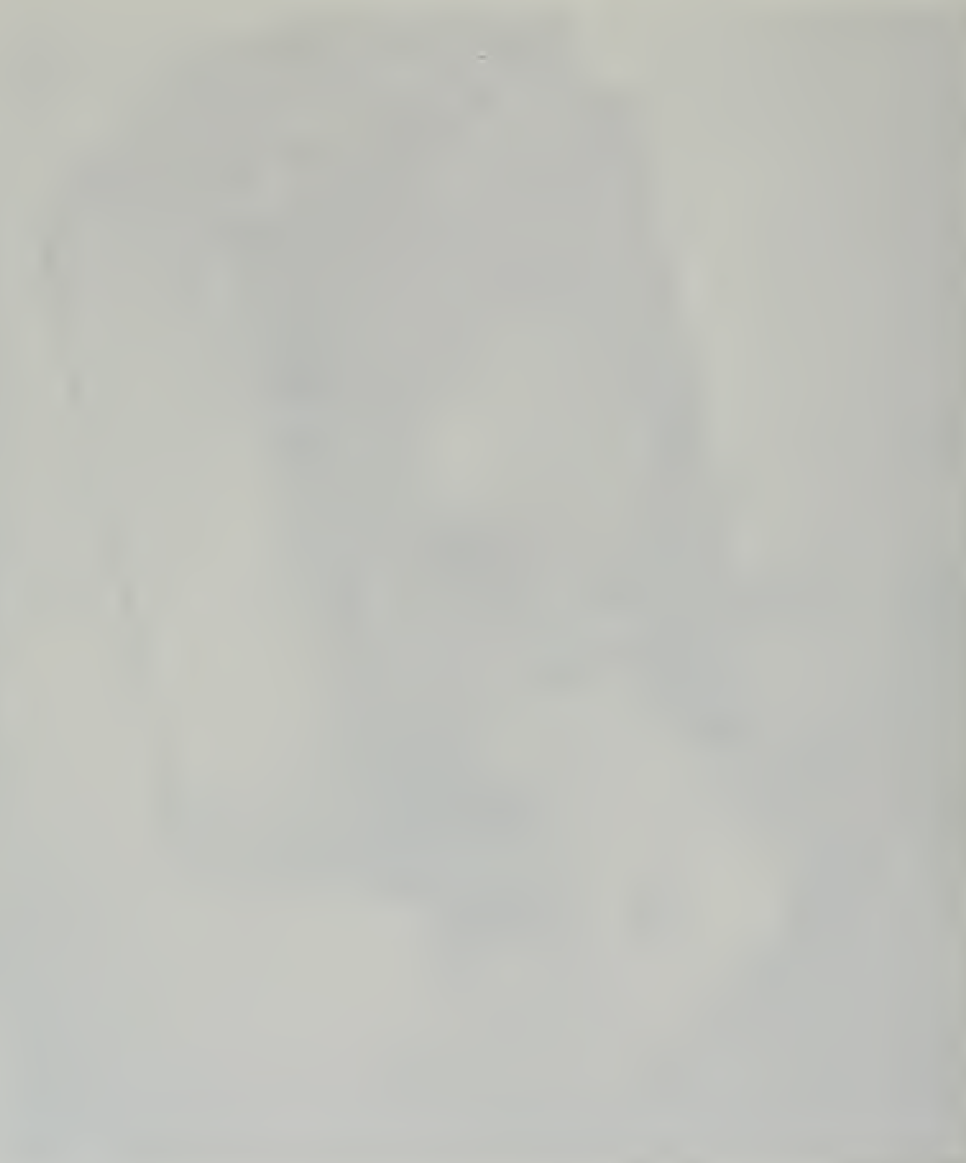


Figure 11. The Dowel Attachment of Shear Box Halves



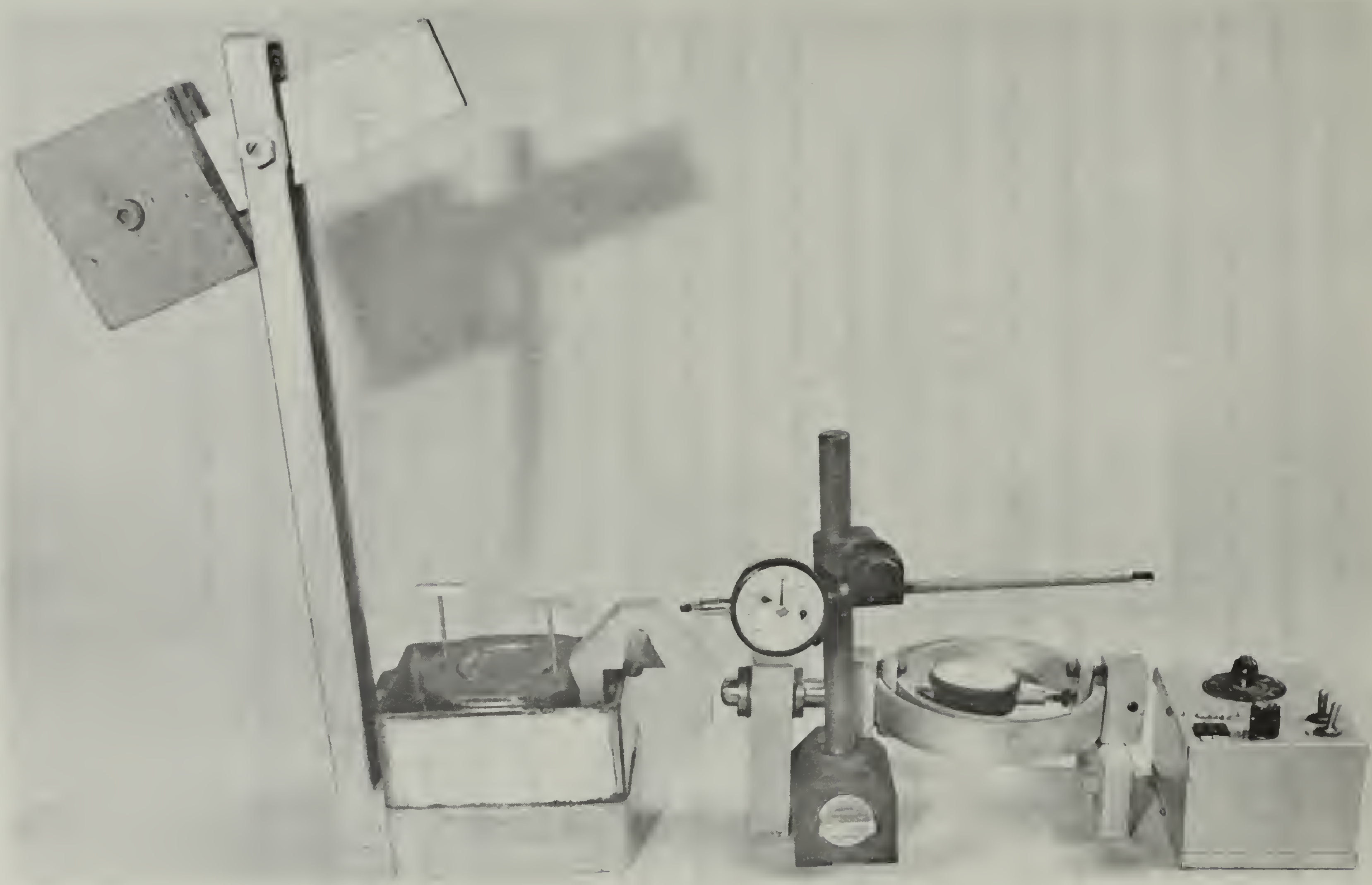


Figure 12. Shear Force Mock Up

2. Proving Rings

An integral part of the strain-controlled shearing device is the means by which the shear force is being applied to the sample can be determined. In most cases this is accomplished through the use of proving rings, consisting of a spring steel ring calibrated as to force required to deflect it a unit length. Figure 13 shows the proving ring unit utilized with this shear apparatus and the dial gauge to measure the deflection. The proving ring unit used had a measured force per displacement factor of 3 lb. per .0001 inch.

3. Drive Mechanism and Speed

The force to the sediment sample is applied by a one-quarter horse-power motor through a reduction box connected to a worm gear assembly with the worm gear directly applying the shear force to the proving ring. In order to achieve fuller and more positive control, a varistat was added to the original soiltest device (Figure 14) allowing various speeds to be applied to the worm gear.

In that the unconsolidated-undrained shear tests require that failure occur in approximately three minutes, it was necessary that a speed of advance of the worm drive be selected with this in mind. A displacement dial gauge was set in place of the shear box bearing surface arm, and tests at various varistat settings were conducted. It was concluded that a speed of .025 inches/minute would be satisfactory to produce a failure in the time required.

Figure 13. The Proving Ring Assembly

Figure 14. The Variable Speed Control

4. Normal Load

The normal load is applied to the test sample by means of the yoke assembly pictured in Figure 15. The upper portion of the yoke applies the load directly to the upper half of the shear block, while the lower portion of the yoke bears the normal load itself.

The normal loading mechanism used for this testing consisted of a water-filled container. Specific amounts of water were weighed and added to the container attached to the lower portion of the yoke. This permitted the changing of normal loads quickly and precisely in that much closer tolerances could be achieved with water than was possible with weights.

B. TEST FORMAT

1. Marine Sediment Properties

The standard sediment used in this series of tests was obtained by R. J. Smith from the tidal flats of Seal Beach Lagoon, Seal Beach, California. Standard laboratory tests of the sediment sample were made and are listed in Table 1. The two results of greatest significance for this investigation were the bulk wet density and water content. As previously noted, these two properties are utilized to determine the weight of solids required for establishment of the normal loads. Average values were determined as BWD = 1.508 g/cc and WC = 78%.

2. Selection of the Normal Load

To obtain the normal stress, σ_N, versus shear stress, τ, curve, at least three different normal loads must be applied. It was decided that normal loads representing depths into the bottom of ten feet, six feet, and two feet be used in order that a sufficiently wide range of loading be achieved.

Figure 15. The Normal Load Yoke Assembly

INTERVAL (inches)	SB - 1 0 - 3	SB - 1 4 - 7	SB - 2 0 - 3	SB - 2 3 - 6	SB - 3 0 - 3	SB - 3 6 - 9	SB - 4 0 - 3	SB - 5 0 - 2½	SB - 5 2½ - 5	SB - 6 0 - 3	SB - 6 4.5 - 7.5	SB - 7 0 - 3	SB - 7 4.5 - 7.5
COLOR (GSA No.)	5GY 6/1	5GY 6/1	5GY 4/1	5GY 4/1	5GY 4/1	5GY 4/1	5G 4/1	N 3	5Y 5/2	N 3	10YR 5/4	5GY 4/1	5GY 4/1
ODOR	H_2S	H_2S	H_2S	H_2S	H_2S	H_2S	H_2S	H_2S	H_2S	H_2S	H_2S	H_2S	H_2S
BULK WET DENSITY (gm cc)	1.452	1.559	1.473	1.471	1.556	1.556	1.403	1.174	1.158	1.549	1.559	1.491	1.520
VANE SHEAR STRENGTH (psi)	0.364	1.495	0.196	0.152	0.688	0.361	0.859	1.817	1.244	1.056	0.786	0.329	0.354
VANE SHEAR STRENGTH (gm/cm^2)	25.6	105.1	13.8	10.7	48.4	25.4	60.4	127.7	87.5	74.2	55.3	23.1	24.9
REMOLDED STRENGTH (psi)	0.364	1.736	0.069	0.078	0.268	0.211	0.386	0.375	0.045	0.038	0.349	0.098	0.151
REMOLDED STRENGTH (gm/cm^2)	25.6	122.0	4.85	5.48	18.8	14.8	27.1	26.4	3.16	2.67	24.5	6.89	10.6
SENSITIVITY	1.0	0.9	2.8	2.0	2.6	1.7	2.2	4.8	27.7	27.8	2.3	3.4	2.3
WATER CONTENT (%)	82.9	66.3	94.6	89.8	66.7	72.7	87.7	287.3	251.3	69.5	69.5	80.9	77.3
SPECIFIC GRAVITY SOLIDS	2.914	3.019	2.735	2.754	2.768	2.734	2.744	2.438	2.506	2.772	2.754	2.788	2.736
DRY DENSITY (gm/cc)	0.794	0.937	0.757	0.775	0.933	0.901	0.747	0.303	0.330	0.914	0.920	0.824	0.857
VOID RATIO	2.676	2.226	2.610	2.559	1.967	2.030	2.676	7.065	6.576	2.030	1.994	2.378	2.226
POROSITY (%)	72.8	69.0	72.3	71.9	66.3	67.0	72.8	87.6	86.8	67.0	66.6	70.4	69.0
SATURATED VOID RATIO	2.416	2.002	2.587	2.473	1.846	1.988	2.406	7.004	6.298	1.927	1.914	2.555	2.136
PERCENT SAND	6.0	2.0	14.0	13.0	24.0	22.5	20.3	18.3	15.9	16.0	12.0	32.5	30.3
PERCENT SILT	30.0	18.0	48.8	49.7	42.0	43.0	43.4	34.1	38.7	55.0	58.0	35.7	34.0
PERCENT CLAY	64.0	80.0	37.2	37.3	34.0	34.5	36.3	47.6	45.4	29.0	30.0	31.8	35.7
MEDIAN DIAMETER (mm)	0.0020	0.0018	0.0096	0.0100	0.0130	0.0135	0.0115	0.0060	0.0065	0.0137	0.0142	0.0170	0.0128
ORGANIC CARBON (%)	1.385	0.578	1.457	1.387	1.534	1.556	1.771	9.319	7.097	2.140	2.138	2.259	1.374

Table I. Physical Properties of Sediment Sample

To determine these normal loads, and subsequently the normal stress, the procedure as outlined in the previous section was utilized. A sample calculation to determine the normal load and normal stress for a sediment depth of tén feet is:

$$WC = 78\%$$
$$BWD = 1.508 \text{ g/cc}$$
$$\text{Diameter of shear box} = 2.5 \text{ in}$$

Therefore: $WS = BWD \times WC = 1.508\ (.78)$
$$WS = 1.17624 \text{ g/cc}$$

Volume of 10 ft. sediment column
$$V = 120\ (4.91) = 590 \text{ in}^3$$

$$V = 590 \text{ in}^3 \ \left(16.4 \frac{\text{cm}^3}{\text{in}^3}\right) = 9670 \text{ cm}^3$$

$$\text{Normal load} = 9670 \times 1.17624$$
$$= 11370 \text{ g}/454 \frac{\text{g}}{\text{lb}}$$

$$\underline{\text{Normal load}} = 25 \text{ lb}$$

$$\sigma_N = \frac{\text{Normal load}}{\text{Area}} = \frac{25}{4.91}$$

$$\sigma_N = 5.1 \text{ lb/in}^2$$

Table 2 lists the required normal loads and normal stresses at the specified depths.

3. Shear Box Friction Factor

In that the upper and lower halves of the shear box were in contact, not all of the applied shear force was transmitted to the sediment sample. Some of the force was taken up by friction between the two halves. In a drained or consolidated sample where escape of pore water is not critical, such friction may be reduced by use of ball bearing spacers or with a lubricant. However, this can not be done in testing a sediment in an unconsolidated-undrained state, as a direct

Penetration Depth (ft)	Normal Load (lb)	Normal Stress (lb/in^2)
10	25	5.1
6	15	3.06
2	5	1.02

Table II. Selected Bottom Penetration Depths and Corresponding Normal Loads

contact affords the best prevention of pore water escape. It was therefore necessary that a friction factor be determined. A shear force of four and one half pounds was necessary to slide the upper half of the shear box over the lower half. As the shape of the surface contact area of the box was irregular (Figure 8) the planimeter pictured in Figure 16 was used to determine this surface area, which was found to be 8.13 square inches. This represented a friction factor of 0.55 pounds per square inch.

4. Dial Gauge Arrangement

To obtain correct and rapid values of shear force, a dial gauge was mounted inside the proving rings as pictured in Figure 13. Similarly, in order to measure the horizontal displacement, a dial gauge was mounted on the test device frame by means of a magnet. This dial rested against an arm mounted normal to the brace attached to the upper half of the shear box (Figure 17). Immediately prior to commencing a test run, readings were taken from all dials to indicate their initial settings.

5. Test Run Procedure

After reading the initial gauge settings, the desired speed of advance of the shearing force was selected and set on the varistat. The required weight of water corresponding to the desired normal load was applied to the container assembly. The sediment was then prepared, thoroughly mixed, and placed into the shear box in a fashion so as to ensure that no air pockets or foreign matter were present. The top grating was positioned and the shear box assembly placed on the loading device. The weighed container was attached to the normal load yoke, and the dowels were removed from the upper and lower halves of the shear box and the motor started. Readings of the gauges were taken every 30 seconds until failure occurred.

Figure 16. A Planimeter

Figure 17. Displacement Dial Gauge Assembly

III. TEST RESULTS

Five test runs at normal loads of 25, 15 and five pounds were made, comprising a total of 15 individual runs. If a test result differed appreciably from an established result, this run was discarded and the test redone. As previously noted, air pockets or some foreign objects within the remolded sample could well produce such spurious readings. Plots of shear stress versus displacement were prepared and are presented in Appendix A, while Appendix B shows the plots of shear stress versus normal loading.

The plots of displacement versus shear stress follow a pattern typical of remolded samples, that is, a regular rise of stress until failure, then no change in shear strength with increased displacement. The presence of an angle of internal friction is observed from the plots of shear stress versus normal stress. Appendix C contains individual values of displacement, shear force, and normal force for each individual run.

The fact that an angle of internal friction was present in this sediment is important as it would appear that shear stress is a function of normal load and not independent as assumed. The problems of trafficability, breakout, and penetration noted earlier would be affected by this factor to some degree. The Φ angles indicated from the combined plots in Appendix B range from a low of 19 degrees to a high of 23.5 degrees.

It was noted that in all test runs failure occurred within two minutes, 30 seconds, or below the minimum time of three minutes. The least failure time occurred for the five pound normal load. It took progressively increased time for the 15 pound and 25 pound normal loads. These facts are illustrated in the plots of Appendix B.

IV. CONCLUSIONS

It was initially assumed that sediment samples above the liquid limit would show a very low angle of internal friction when tested in an unconsolidated-undrained state. That is, in accordance with Coulomb's Law, $\tau = C + \sigma_N \tan \Phi$, the shear stress would be independent of the normal load, and that the shear stress would equal the cohesion. In such an event, the shear strength could be directly obtained by a test such as that of the vane shear device at the no-load state.

The tests results from this investigation do demonstrate that this sediment does exhibit an angle of internal friction, seen to vary between 15 and 20 degrees. The slight variation in the Φ angle may be considered to be caused chiefly by foreign particles such as small shells, spurious pieces of relatively large sand, or entrapped pockets of air.

While the use of the vane shear device is convenient for a rapid determination of cohesion, it does not truly define the shear envelope. If this vane shear values are used for engineering purposed, it is necessary that a full understanding of its implications is realized.

[illegible]

[illegible]

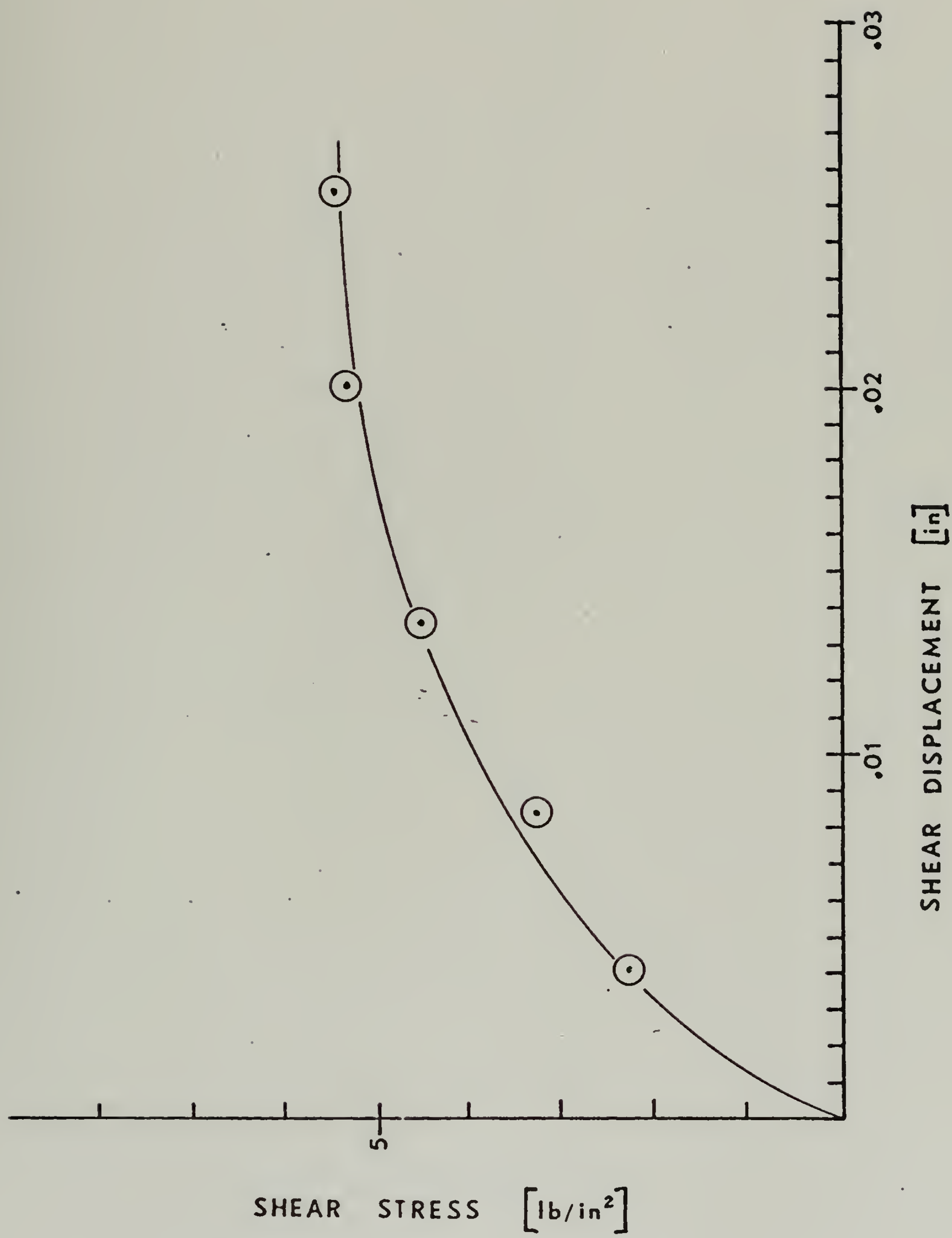
[illegible]

[illegible]

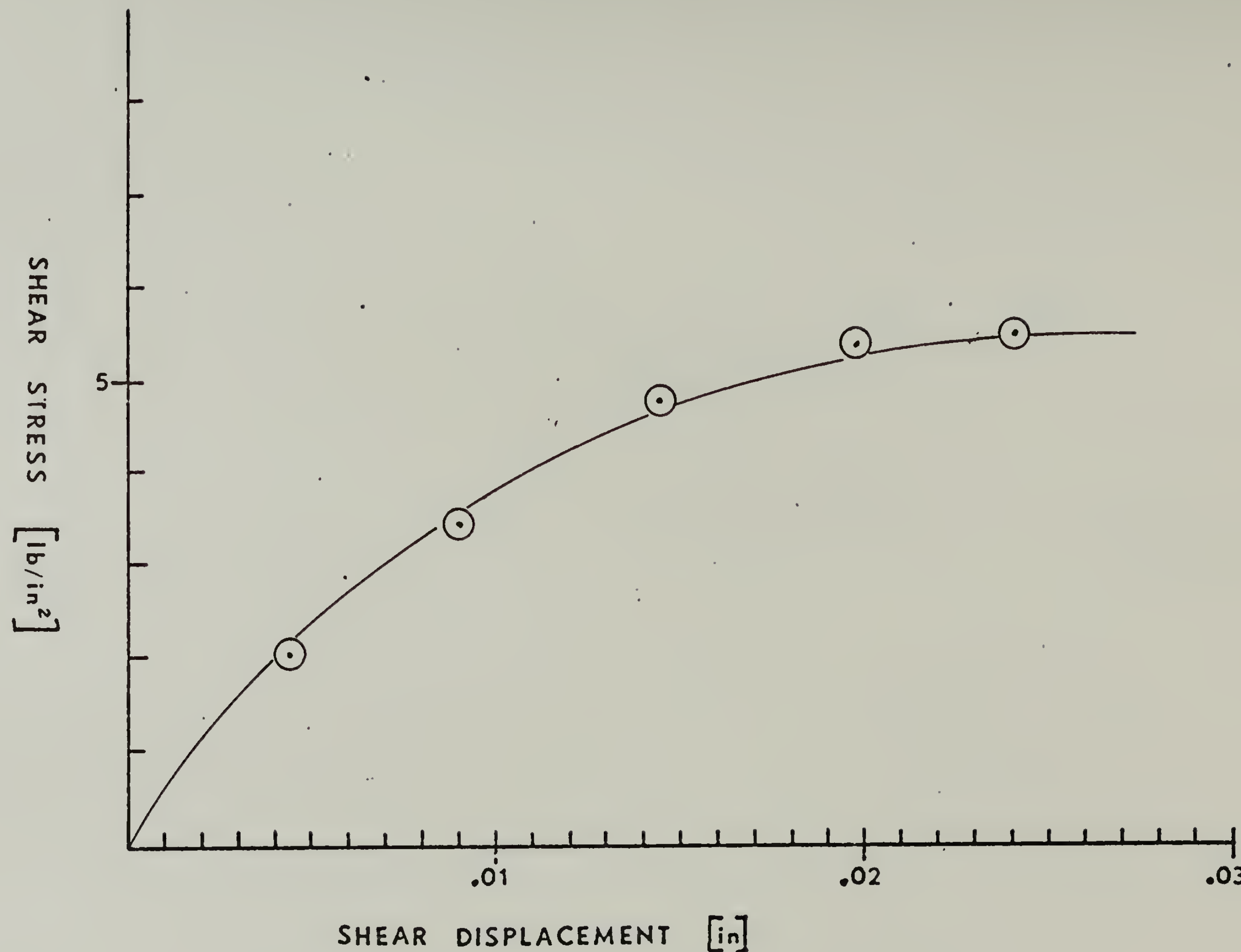
V. FUTURE CONSIDERATIONS

Recent work has resulted in the development of an unconfined compression testing machine [Westfahl 1970] and a vane shear apparatus specifically designed for use with marine sediments [Minugh 1970 and Heck 1970]. The design and development of a direct shear device specifically for these sediments would be extremely useful. A compact, portable, self recording device could be designed without great difficulty.

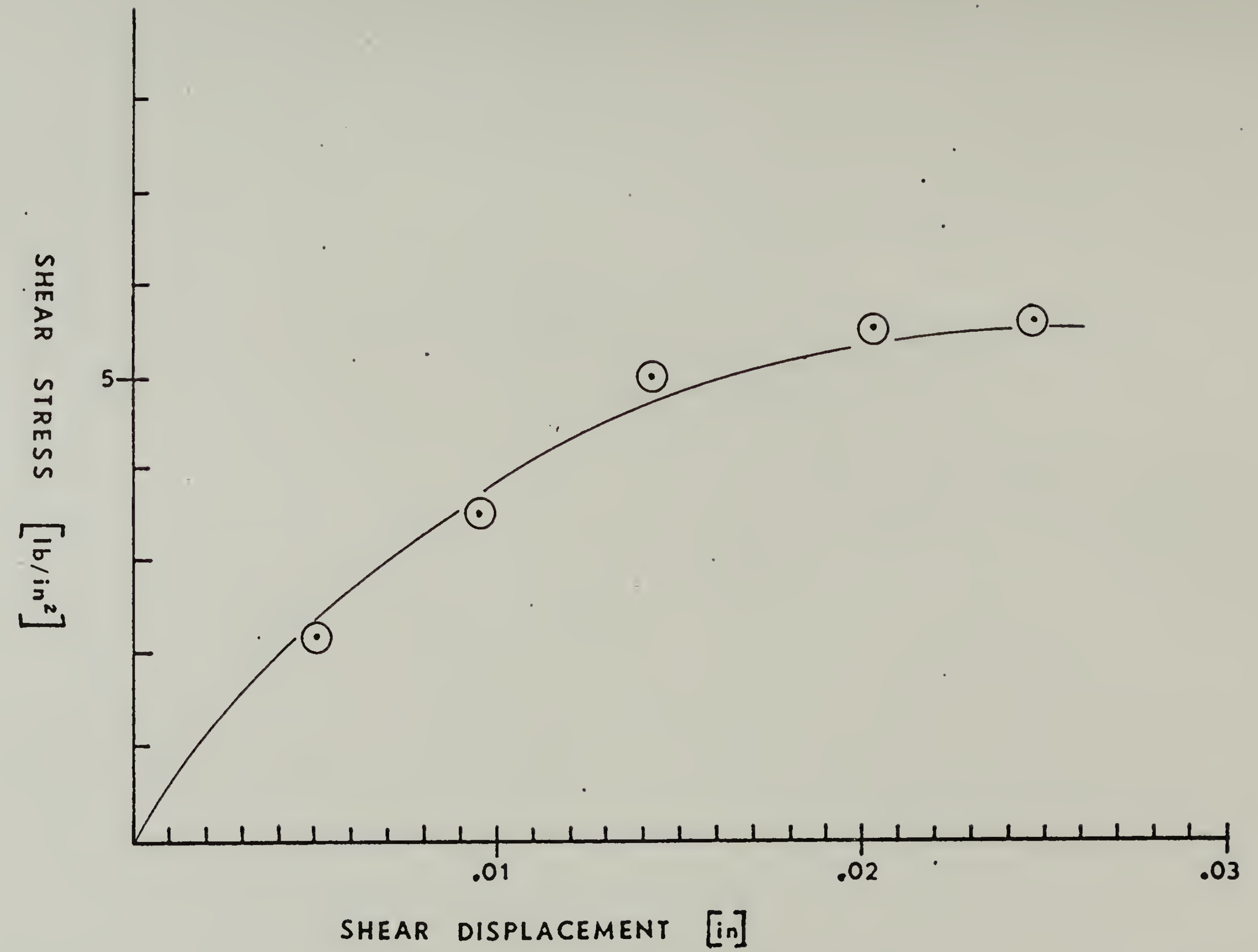
APPENDIX A



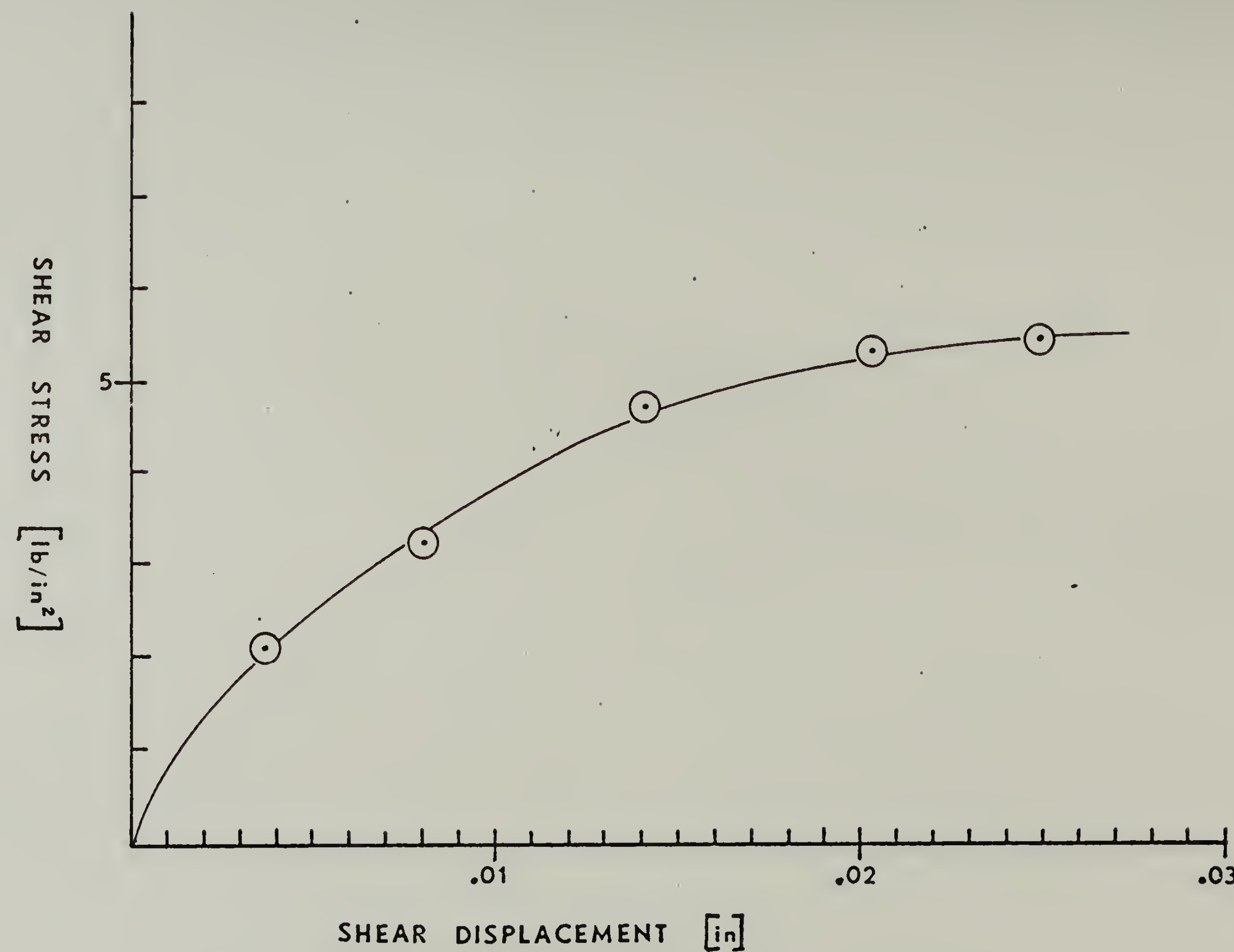
Test Run 1, Normal Load 25 Pounds



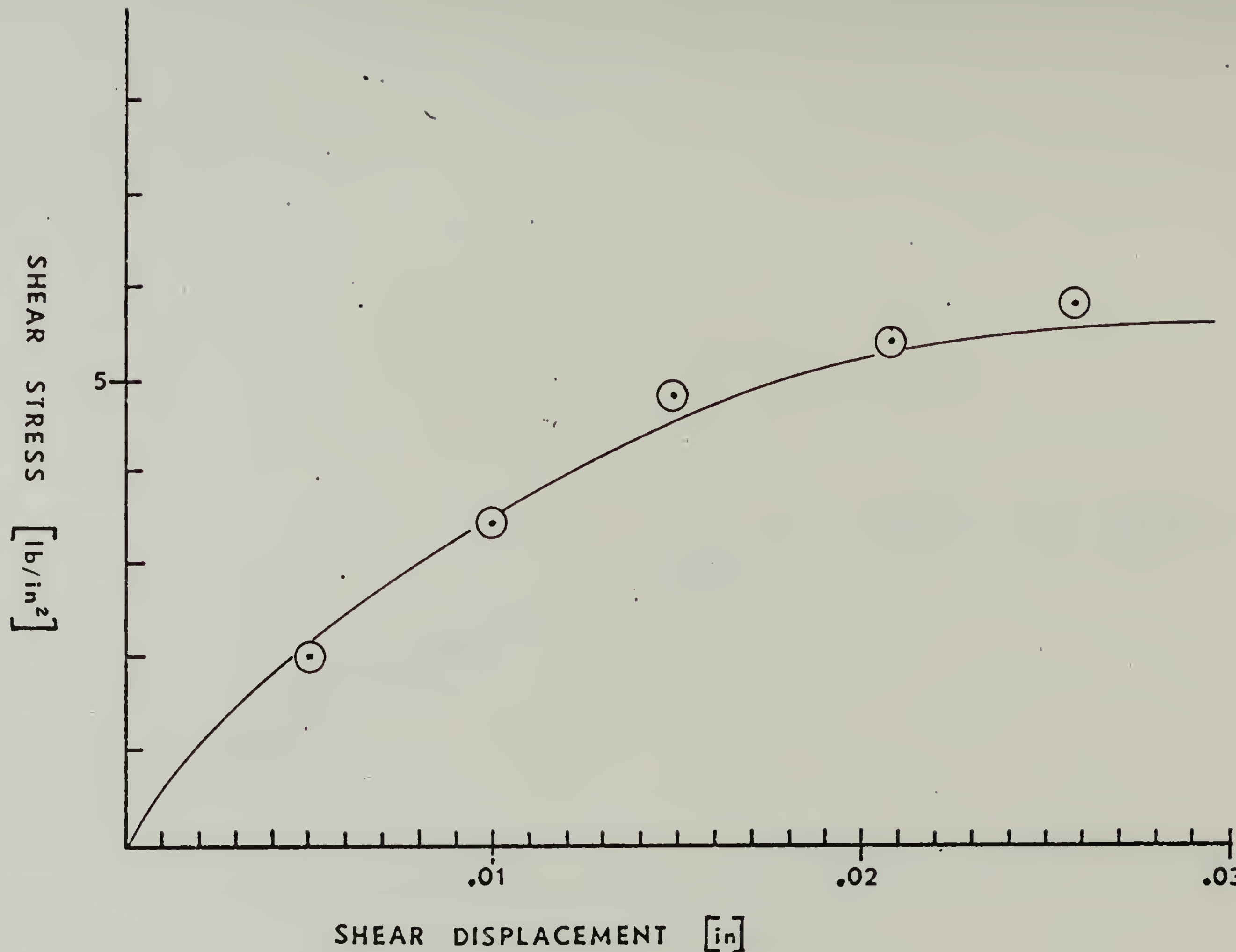
Test Run 2, Normal Load 25 Pounds



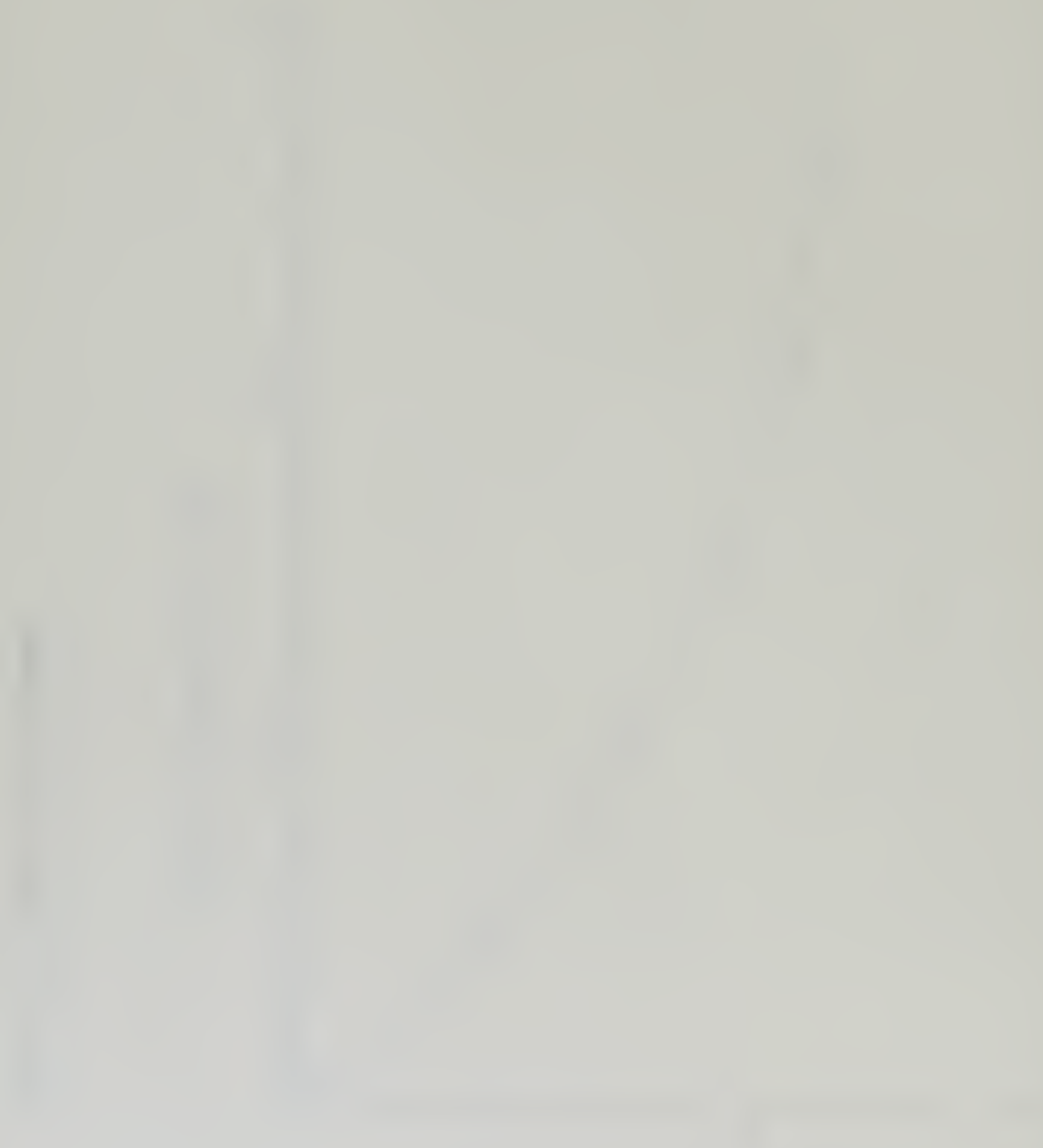
Test Run 3, Normal Load 25 Pounds

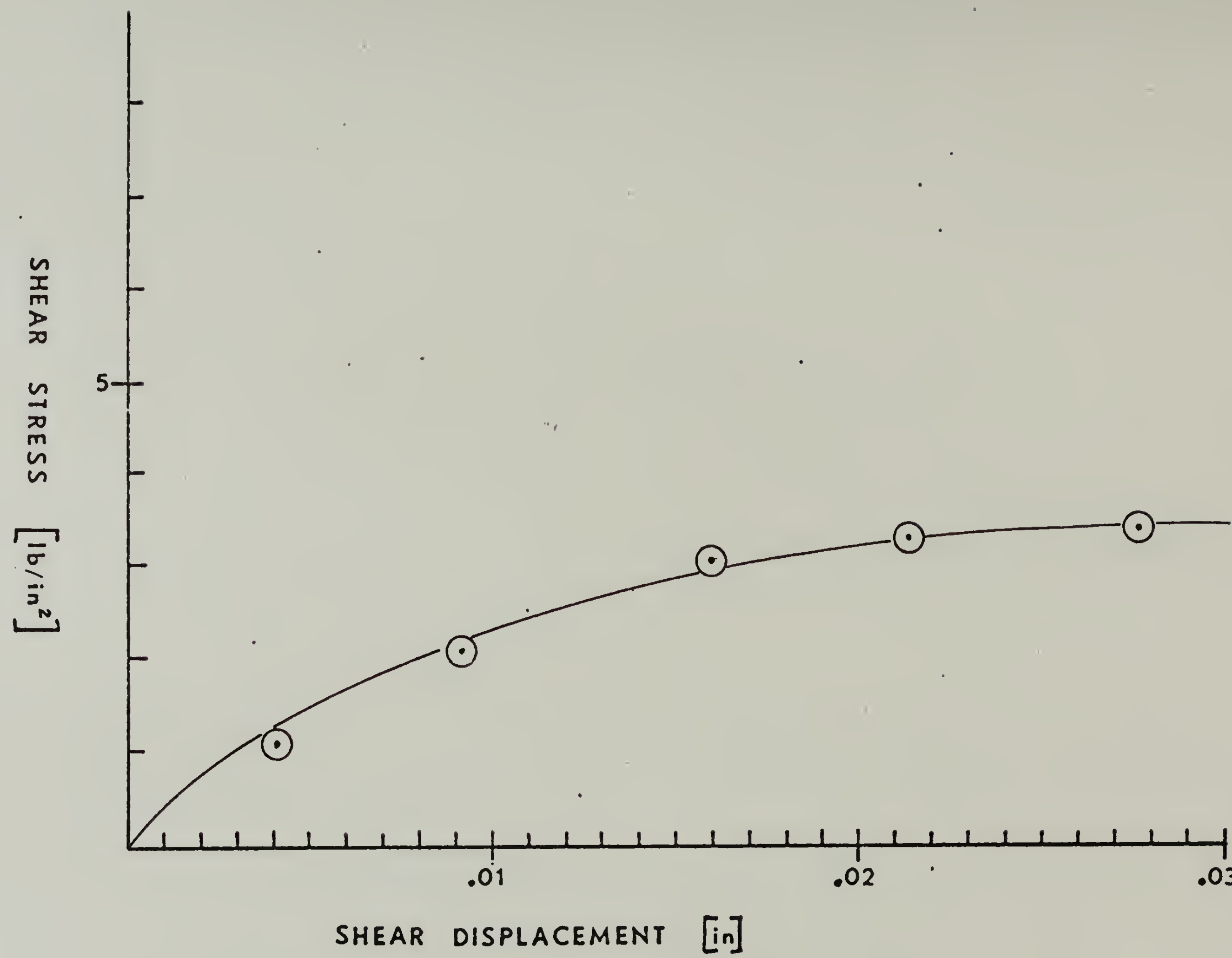


Test Run 4, Normal Load 25 Pounds

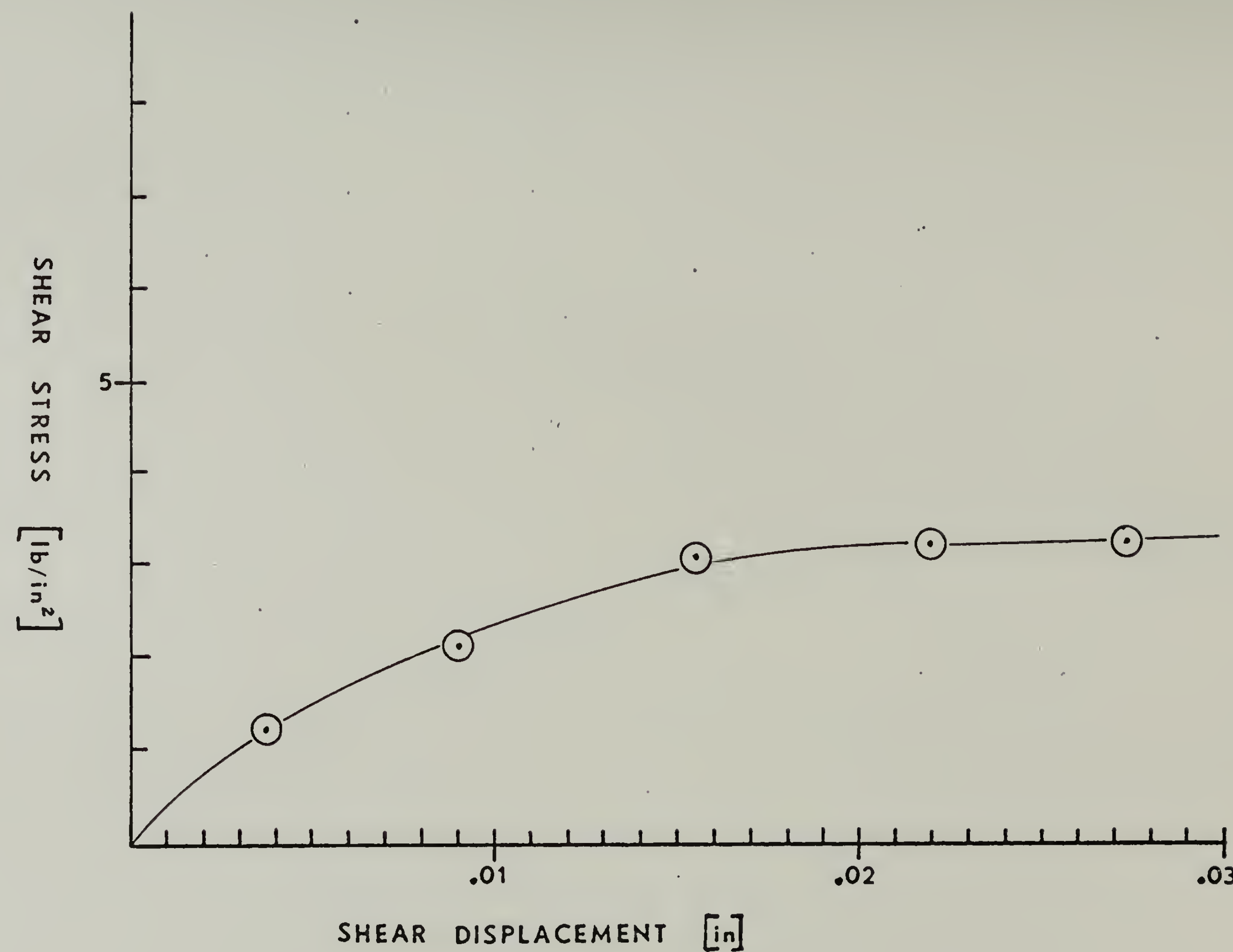


Test Run 5, Normal Load 25 Pounds

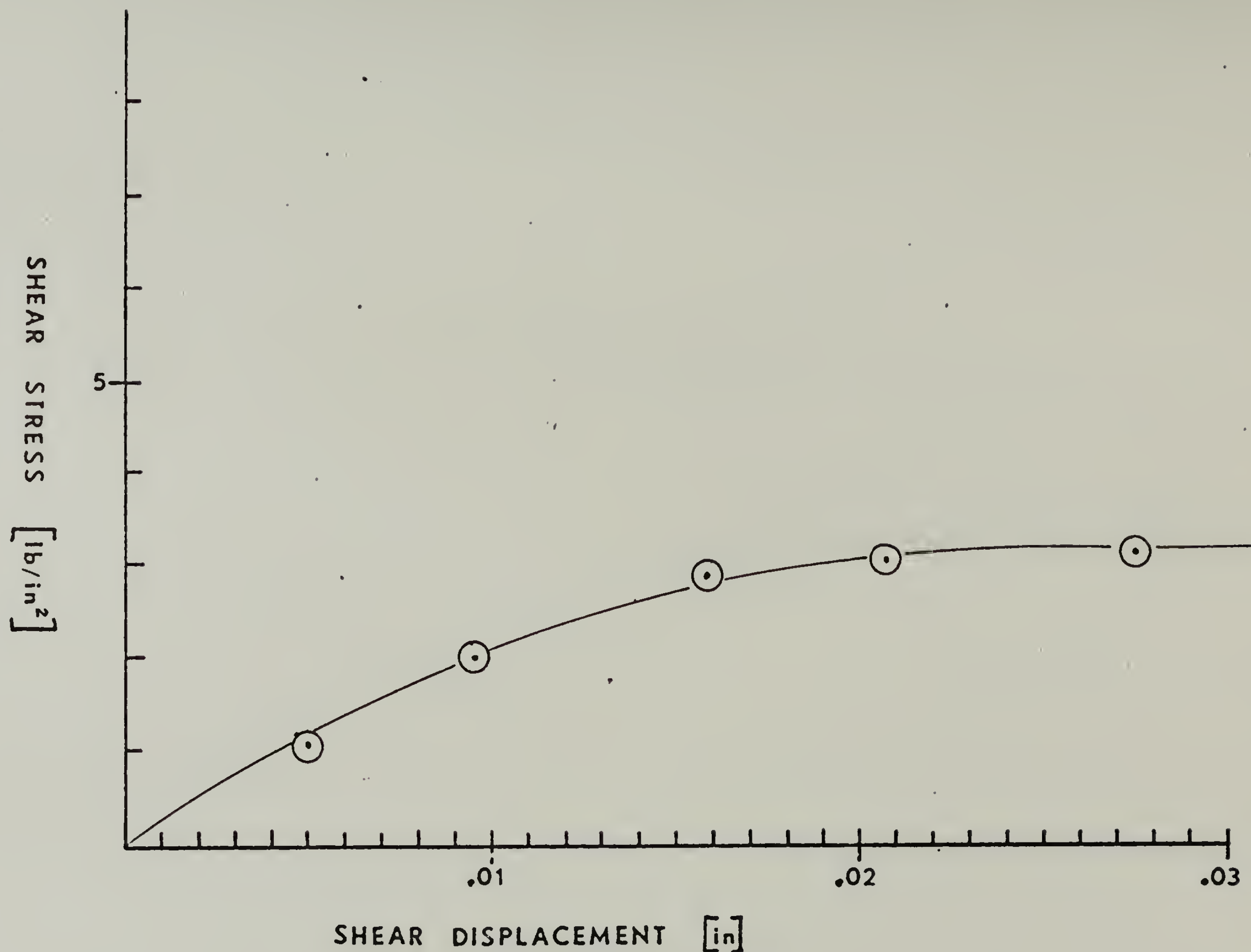




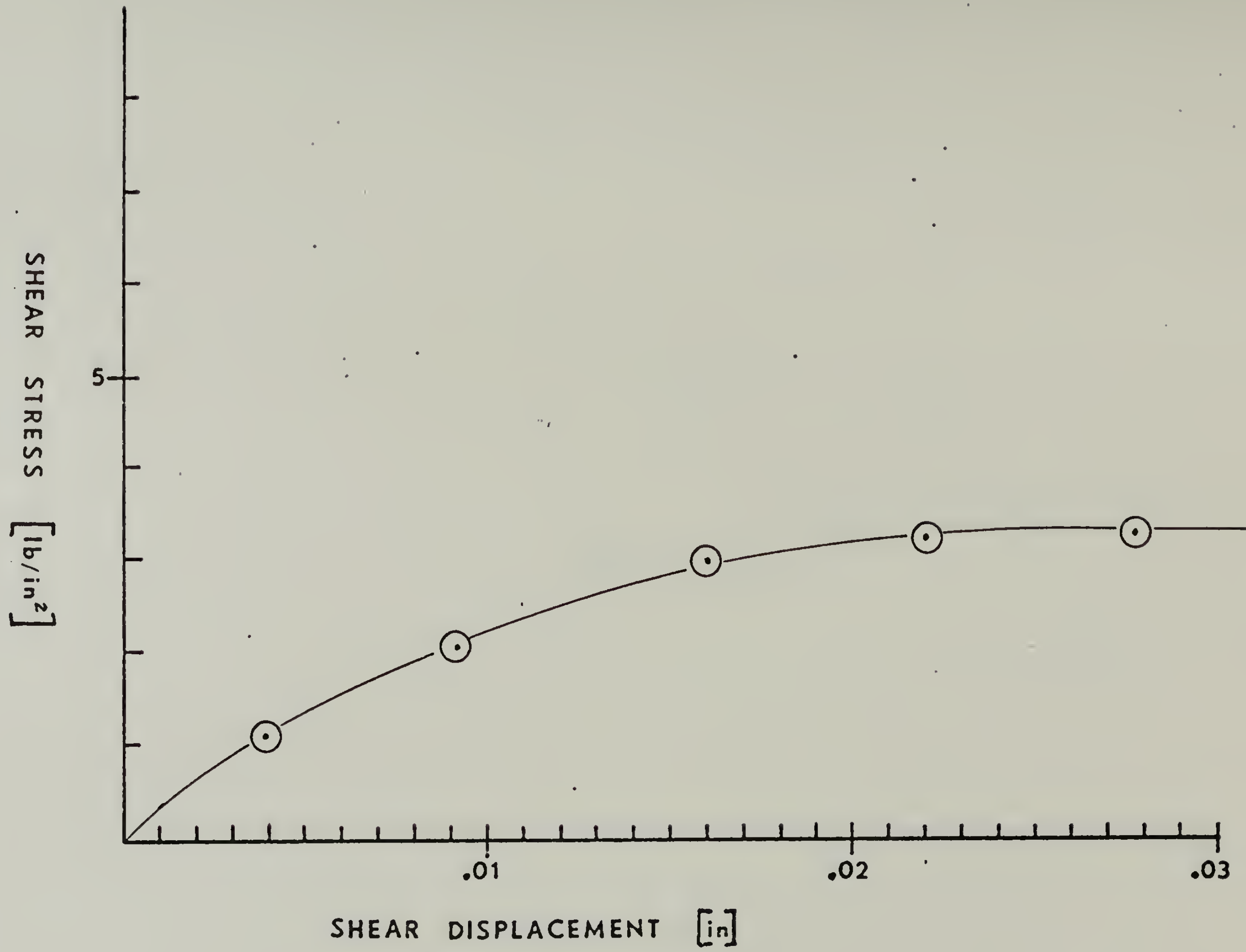
Test Run 6, Normal Load 15 Pounds



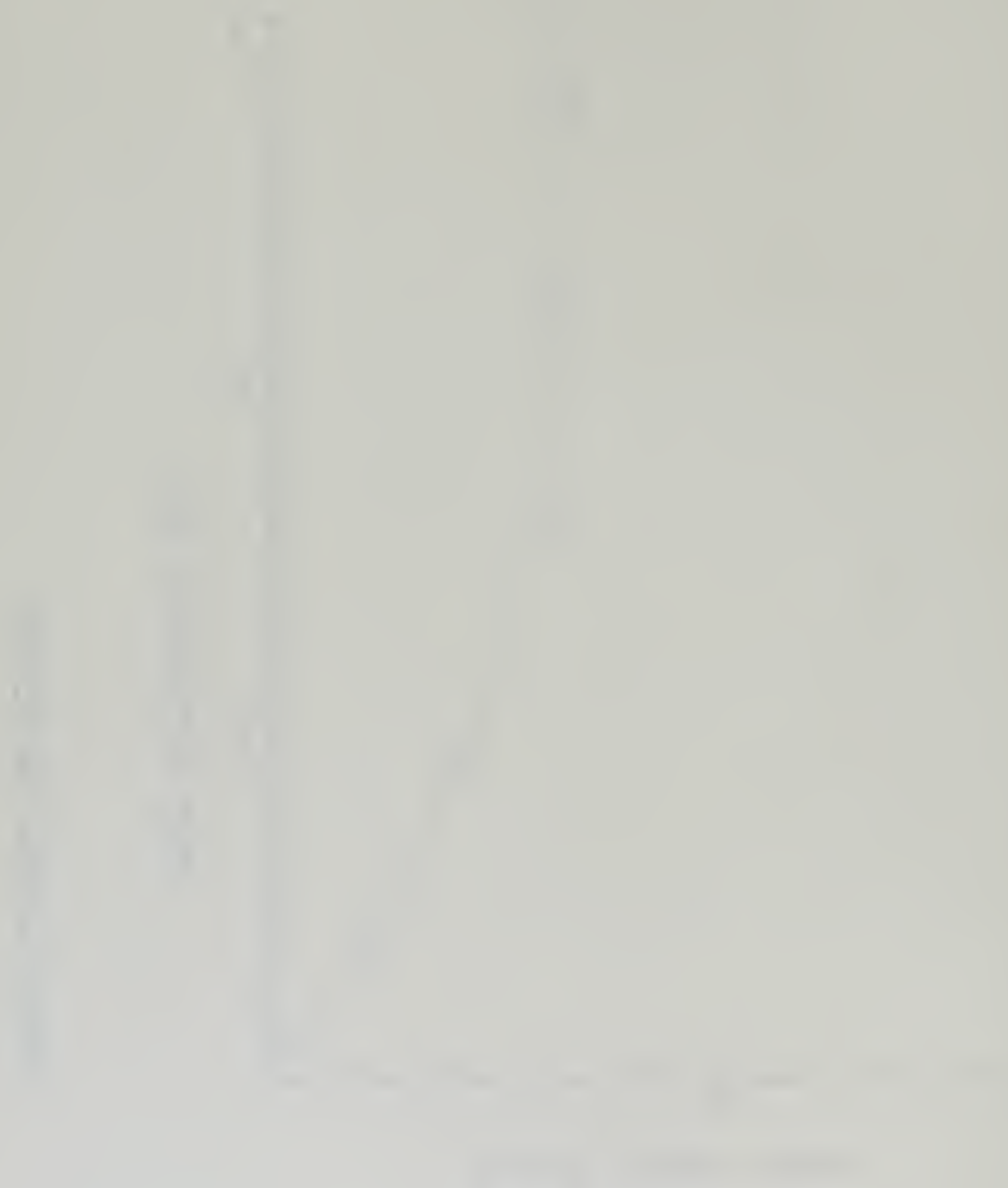
Test Run 7, Normal Load 15 Pounds

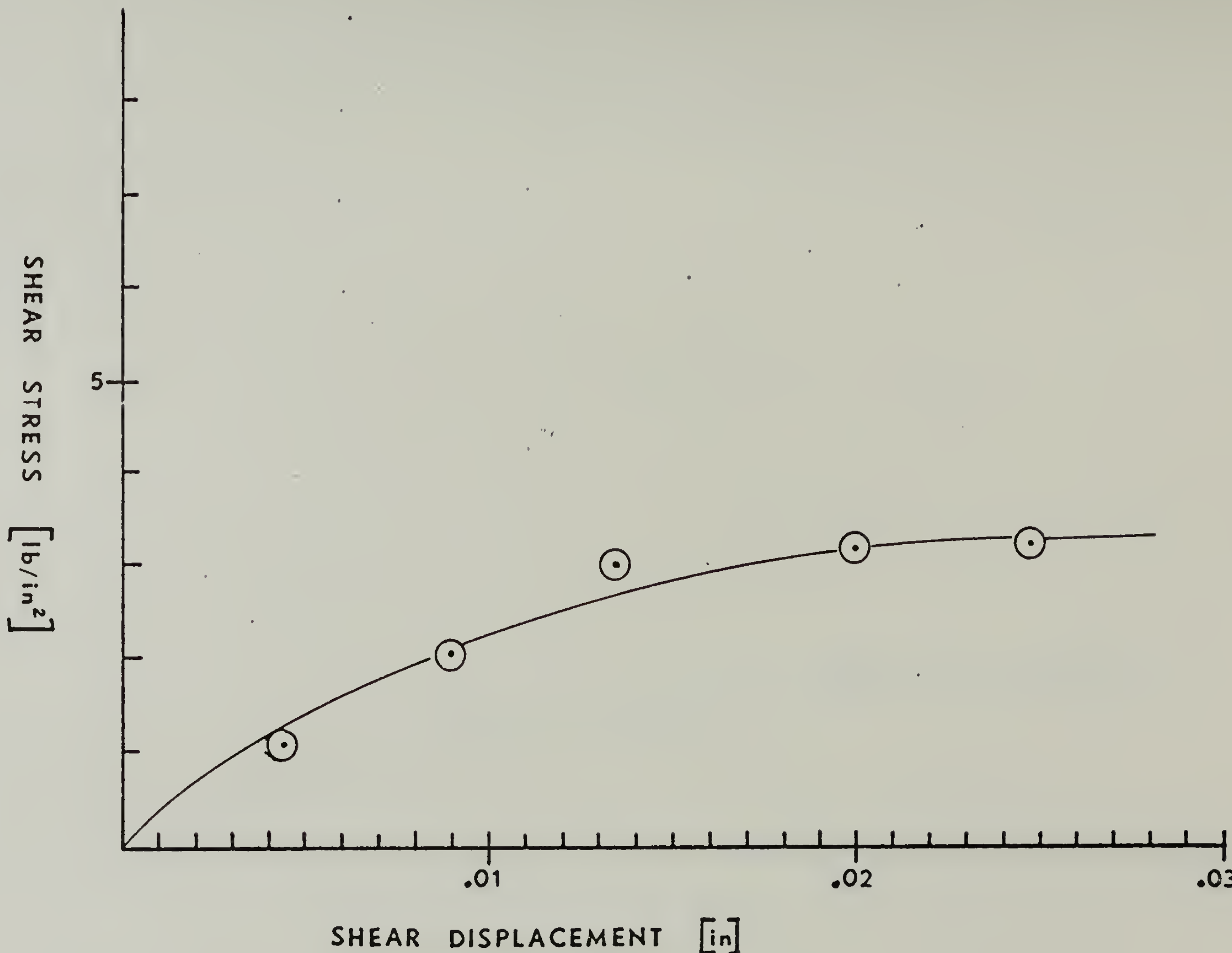


Test Run 8, Normal Load 15 Pounds

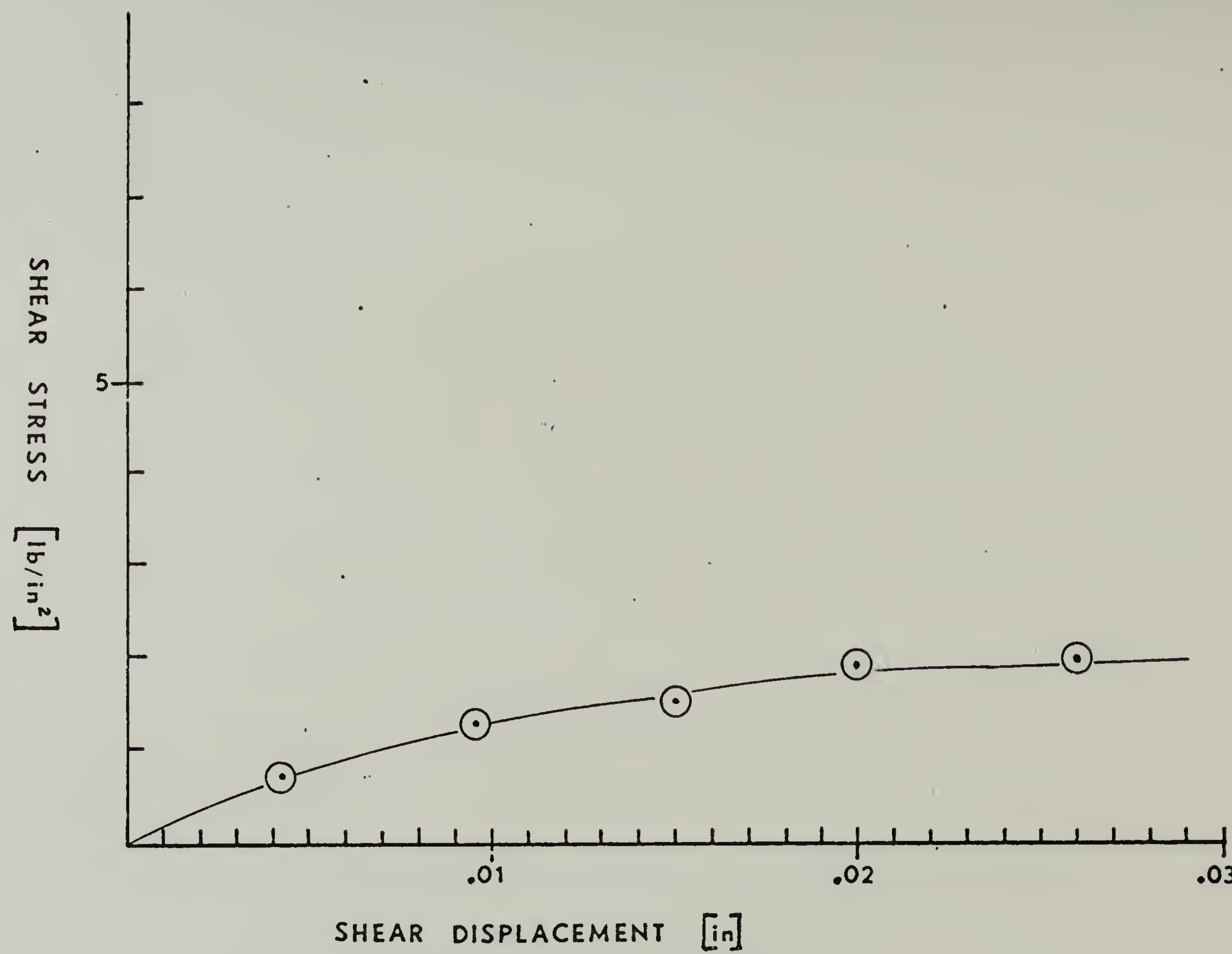


Test Run 9, Normal Load 15 Pounds

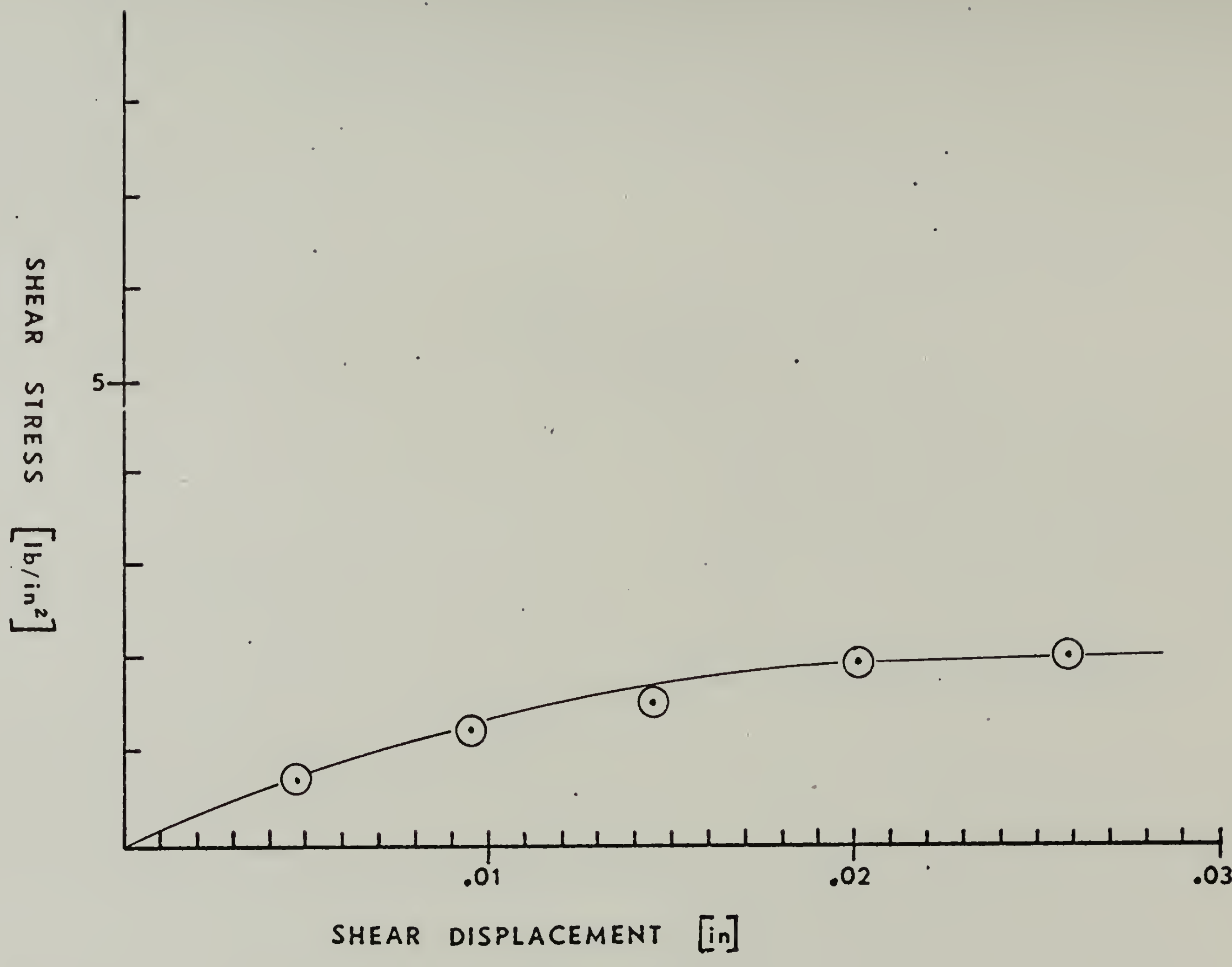




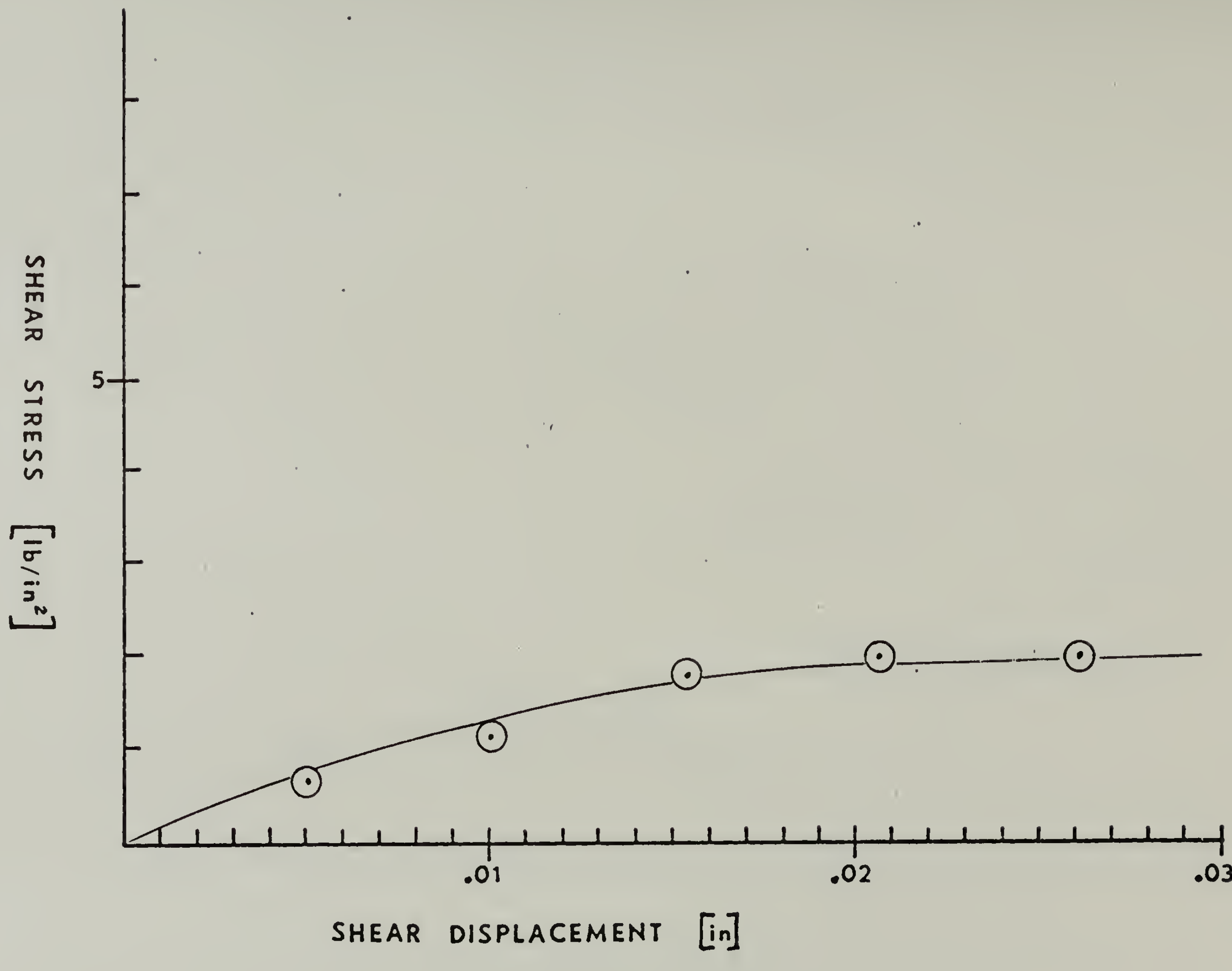
Test Run 10, Normal Load 15 Pounds



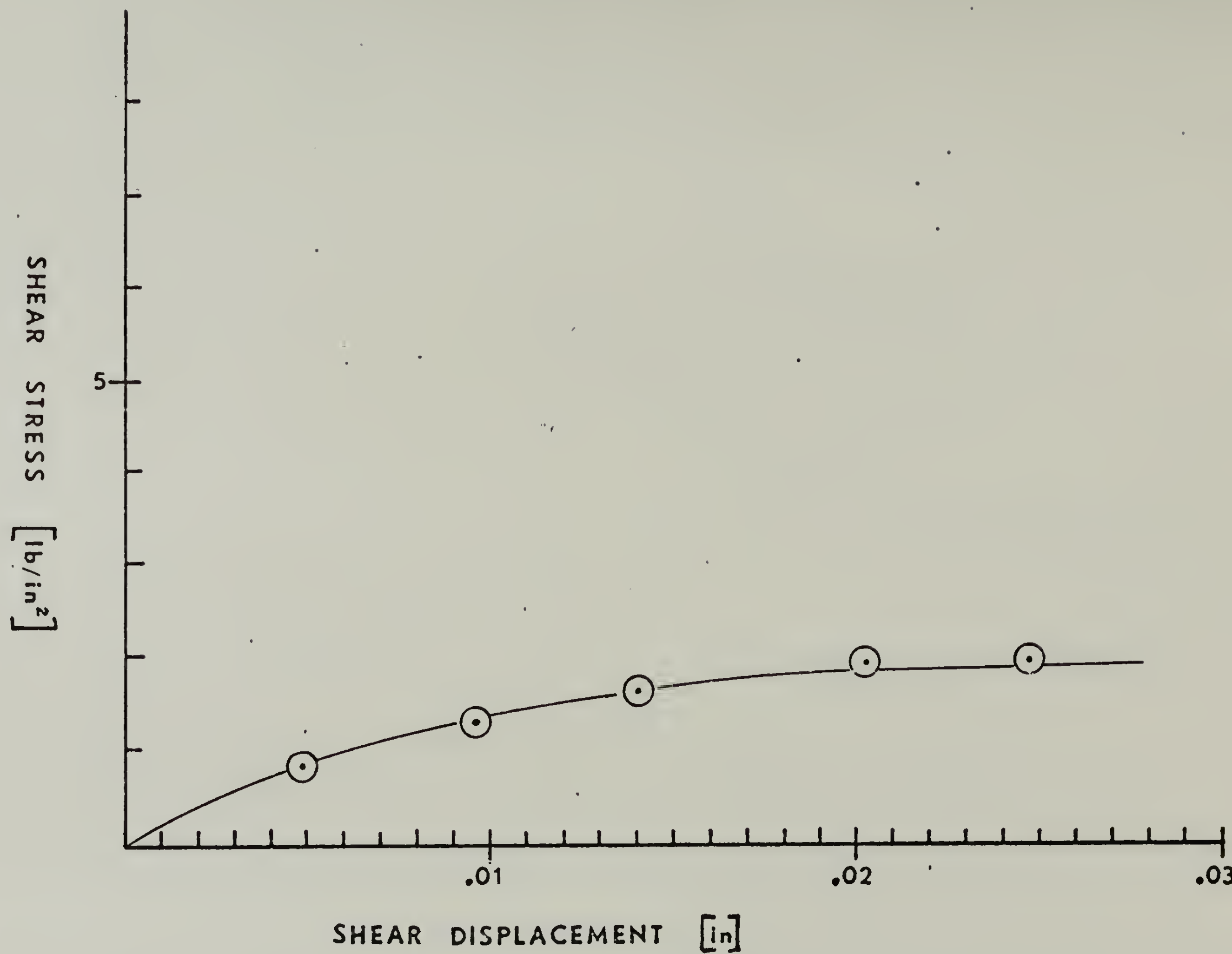
Test Run 11, Normal Load Five Pounds



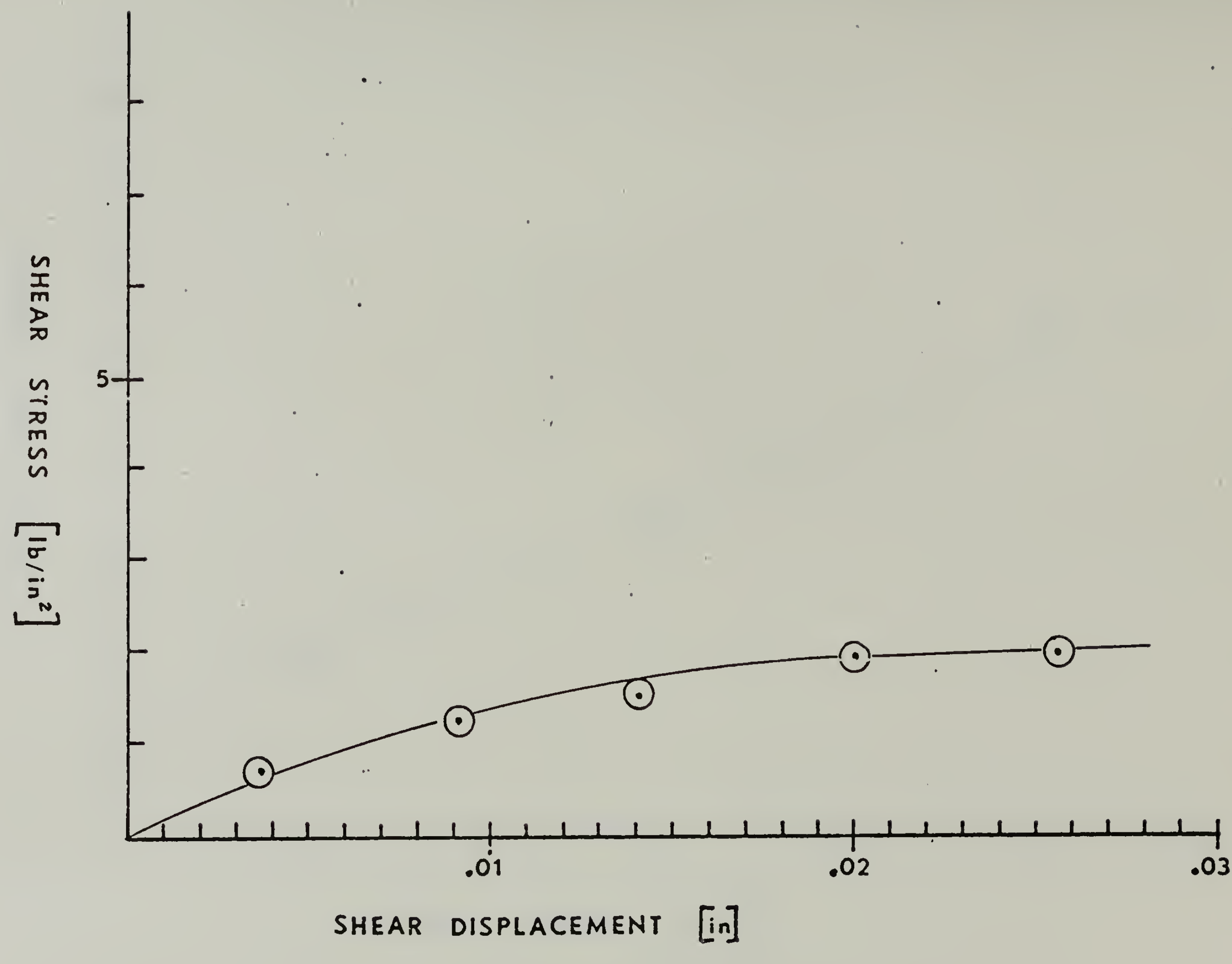
Test Run 12, Normal Load Five Pounds



Test Run 13, Normal Load Five Pounds

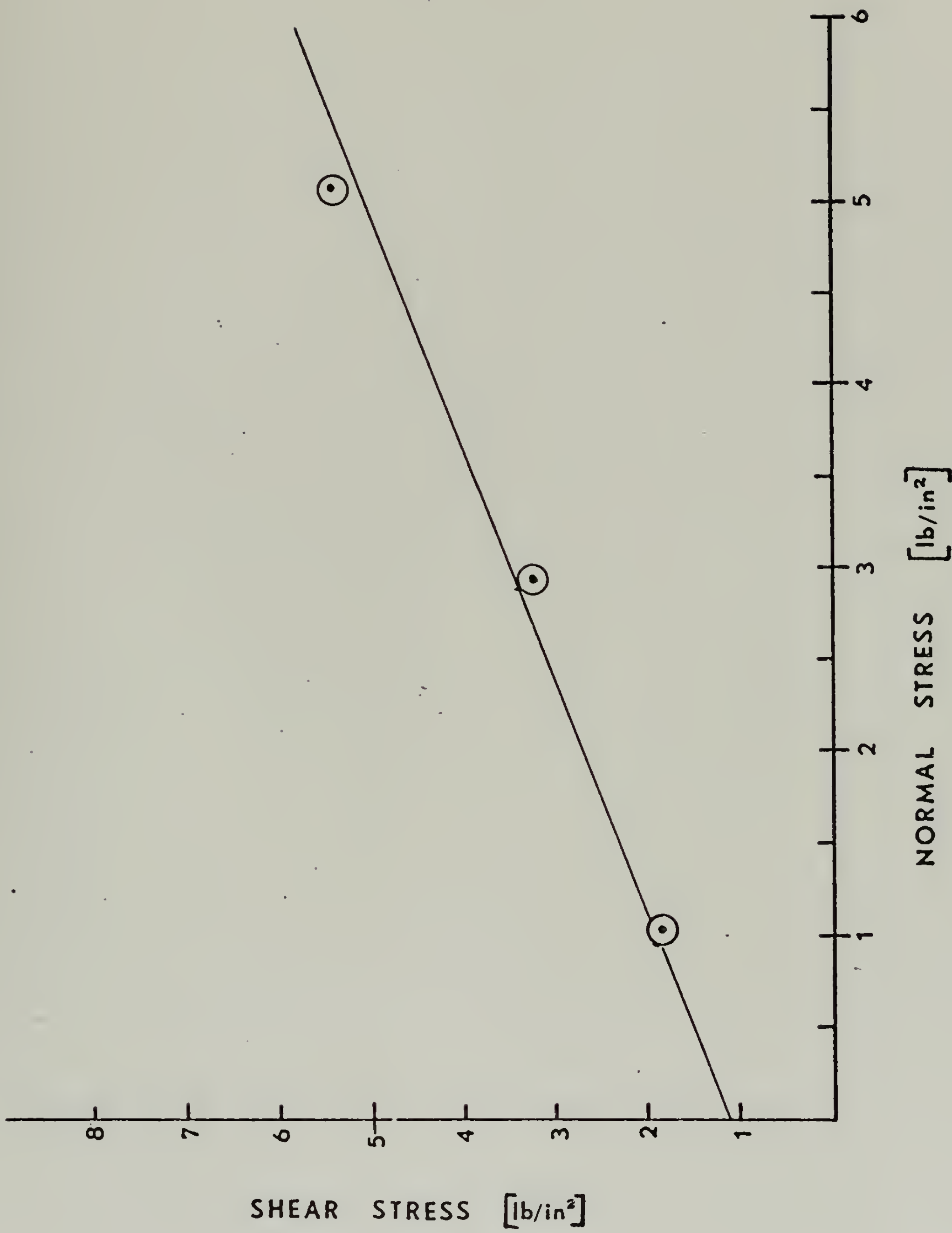


Test Run 14, Normal Load Five Pounds

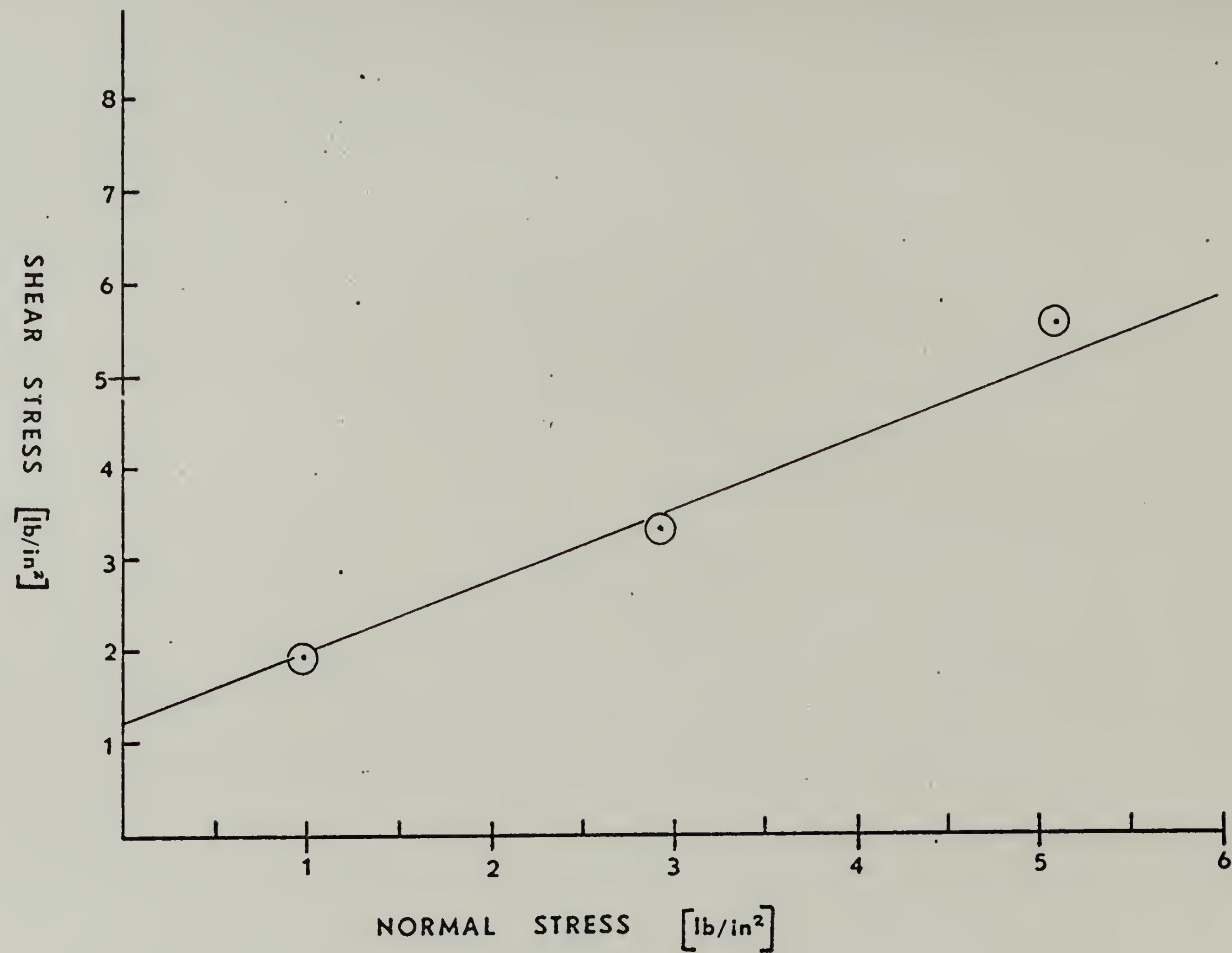


Test Run 15, Normal Load Five Pounds

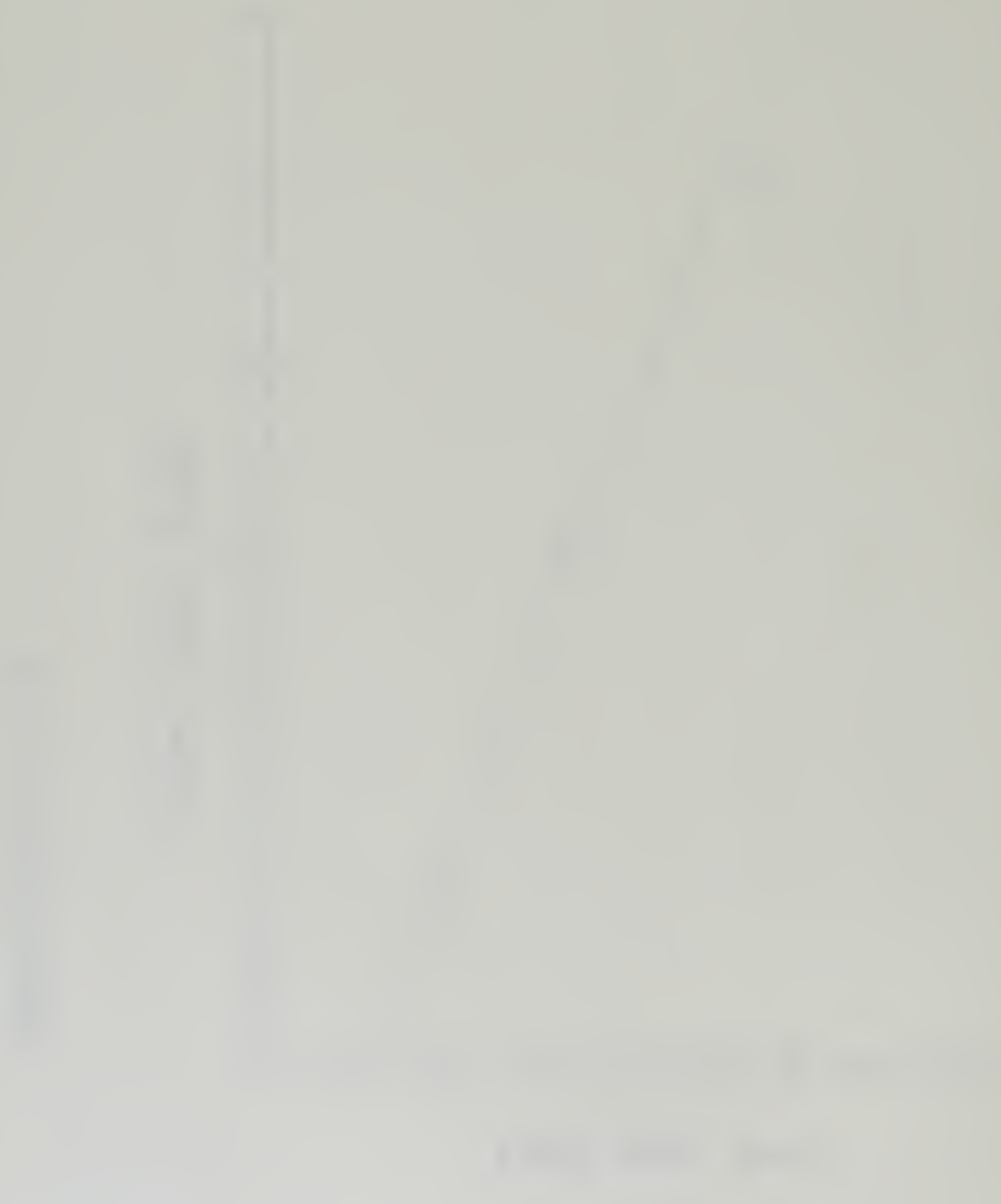
APPENDIX B

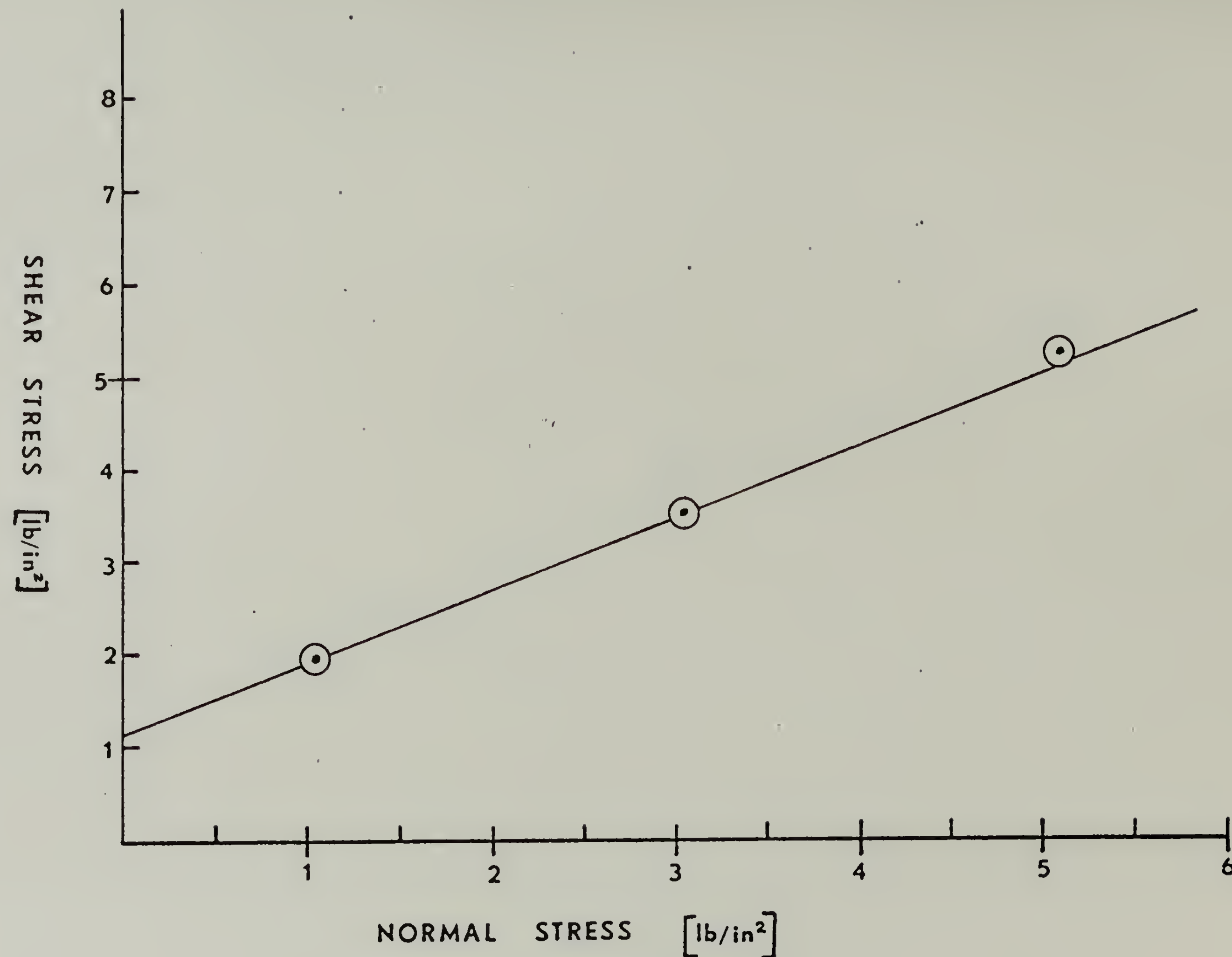


Combined Test Runs 1, 6, 11

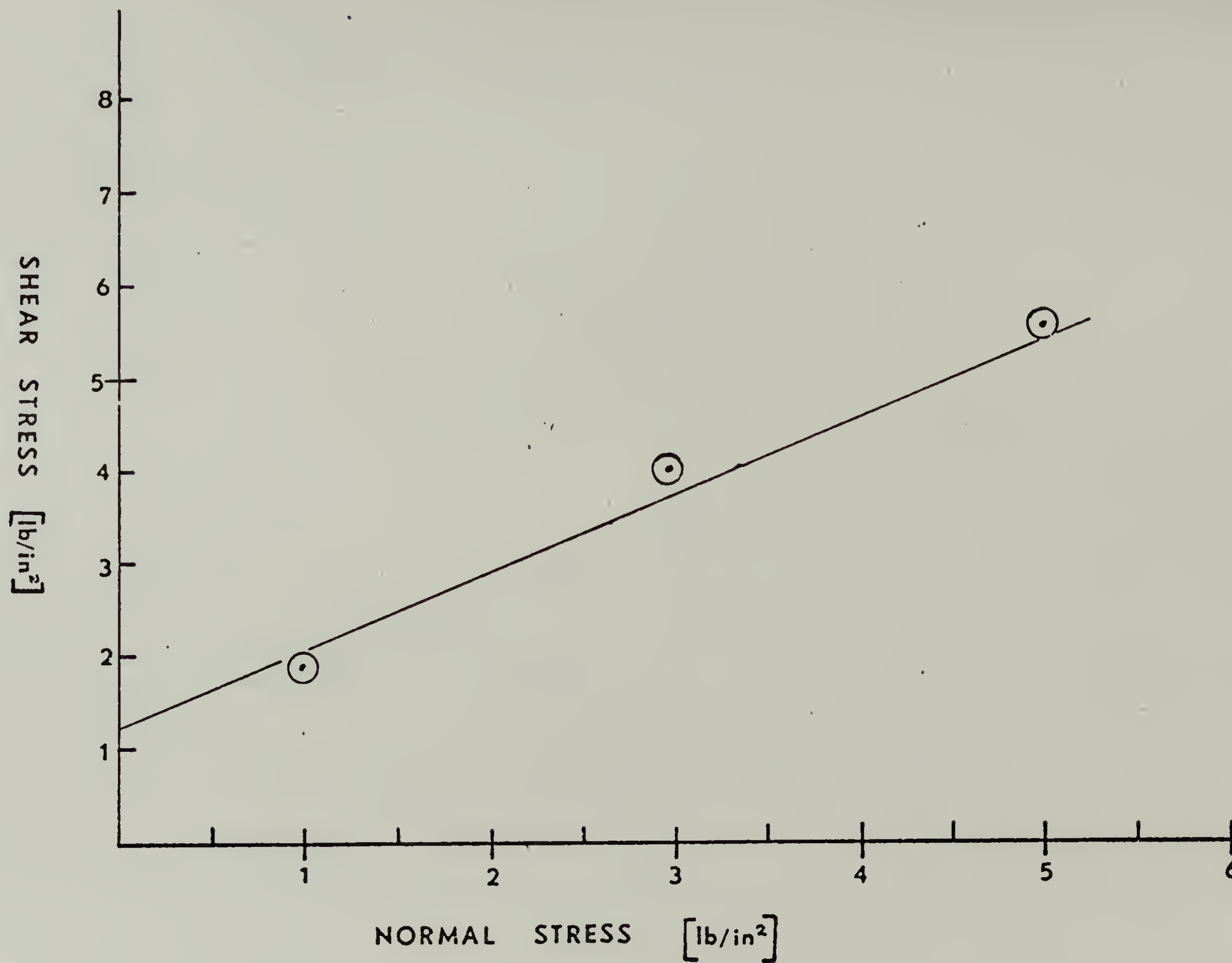


Combined Test Runs 2, 7, 12

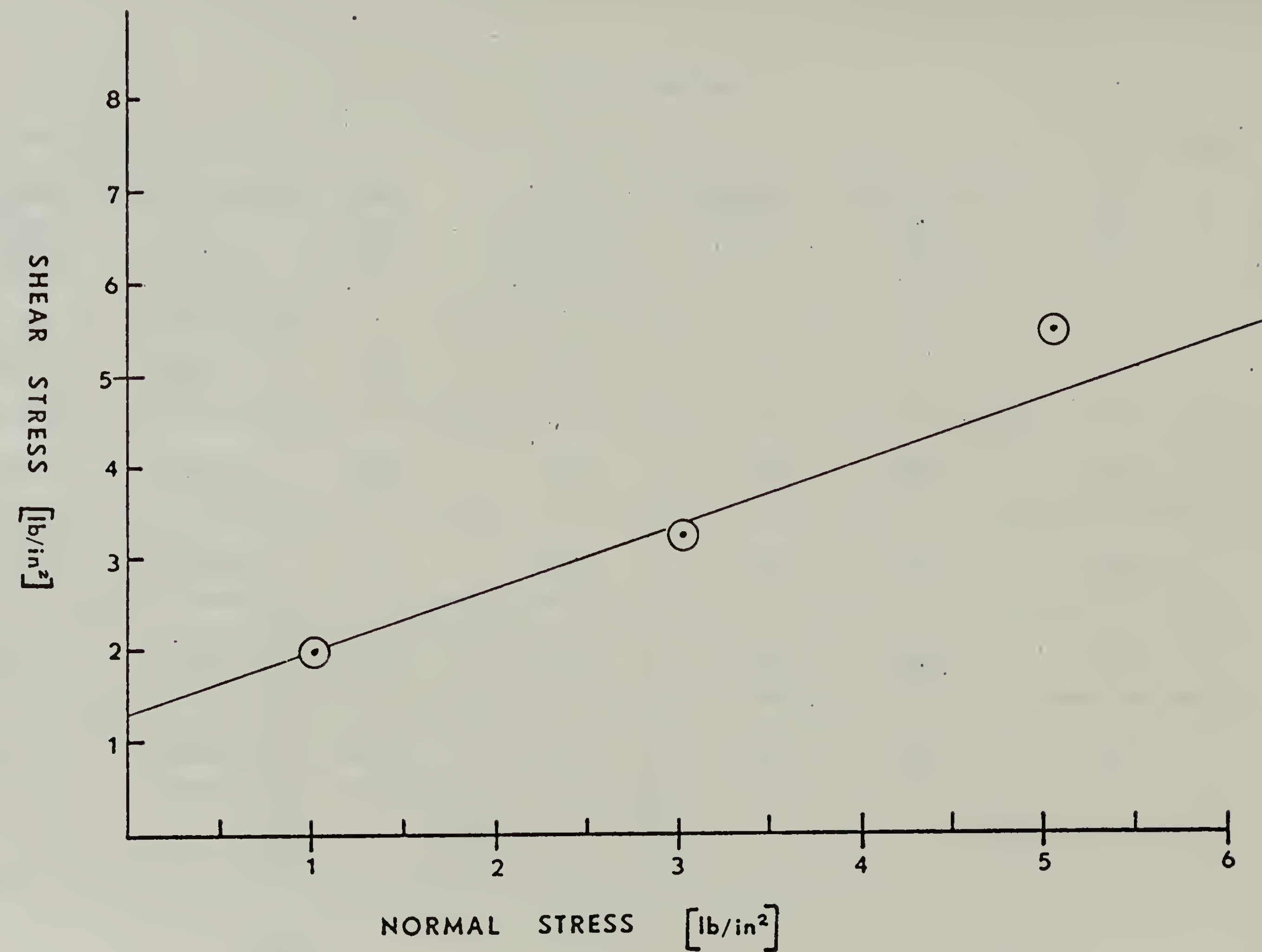




Combined Test Runs 3, 8, 13



Combined Test Runs 4, 9, 14



Combined Test Runs 5, 10, 15

APPENDIX C

TEST RUN DATA

Elapsed Time (min)	Displacement Dial Reading (in)	Shear Force (lb/in^2)	Shear Force Corrected (lb/in^2)	Elapsed Time (min)	Displacement Dial Reading (in)	Shear Force (lb/in^2)	Shear Force Corrected (lb/in^2)
0:30	.004	2.82	2.32	0:30	.0049	2.55	2.05
1:00	.0085	3.83	3.33	1:00	.0091	3.97	3.47
1:30	.0138	5.2	4.70	1:30	.0145	5.40	4.90
2:00	.0200	5.75	5.25	2:00	.0205	5.92	5.42
2:30	.0247	6.00	5.50	2:30	.0240	6.02	5.52

Run 1

Normal Load 25 lb
Normal Stress 5.1 lb/in^2

Run 2

Normal Load 25 lb
Normal Stress 5.1 lb/in^2

Elapsed Time (min)	Displacement Dial Reading (in)	Shear Force (lb/in^2)	Shear Force Corrected (lb/in^2)	Elapsed Time (min)	Displacement Dial Reading (in)	Shear Force (lb/in^2)	Shear Force Corrected (lb/in^2)
0:30	.005	2.75	2.25	0:30	.0038	2.62	2.12
1:00	.0095	3.90	3.40	1:00	.0082	3.75	3.25
1:30	.0144	5.35	4.85	1:30	.0140	5.25	4.75
2:00	.0205	5.80	5.30	2:00	.0205	5.8	5.30
2:30	.0246	5.98	5.48	2:30	.0250	6.02	5.52

Run 3
Normal Load 25 lb
Normal Stress 5.1 lb/in^2

Run 4
Normal Load 25 lb
Normal Stress 5.1 lb/in^2

Elapsed Time (min)	Displacement Dial Reading (in)	Shear Force (lb/in^2)	Shear Force Corrected (lb/in^2)
0:30	.005	2.58	2.08
1:00	.010	4.02	3.52
1:30	.015	5.41	4.91
2:00	.021	5.95	5.45
2:30	.026	6.09	5.59

Run 5
Normal Load 25 lb
Normal Stress 5.1 lb/in^2

Elapsed Time (min)	Displacement Dial Reading (in)	Shear Force (lb/in^2)	Shear Force Corrected (lb/in^2)
0:30	.0042	1.65	1.15
1:00	.0093	2.51	2.01
1:30	.016	3.51	3.01
2:00	.0217	3.65	3.15
2:30	.0283	3.67	3.17

Run 6
Normal Load 15 lb
Normal Stress 3.06 lb/in^2

Elapsed Time (min)	Displacement Dial Reading (in)	Shear Force (lb/in^2)	Shear Force Corrected (lb/in^2)
0:30	.0038	1.70	1.20
1:00	.0090	2.55	2.05
1:30	.0155	3.60	3.10
2:00	.022	3.68	3.18
2:30	.0275	3.69	3.19

Run 7
Normal Load 15 lb
Normal Stress 3.06 lb/in^2

Elapsed Time (min)	Displacement Dial Reading (in)	Shear Force (lb/in^2)	Shear Force Corrected (lb/in^2)
0:30	.0051	1.59	1.09
1:00	.0095	2.50	2.00
1:30	.0158	3.41	2.91
2:00	.0208	3.58	3.08
2:30	.028	3.60	3.10

Run 8
Normal Load 15 lb
Normal Stress 3.06 lb/in^2

Elapsed Time (min)	Displacement Dial Reading (in)	Shear Force (lb/in^2)	Shear Force Corrected (lb/in^2)
0:30	.004	1.68	1.18
1:00	.0094	2.52	2.02
1:30	.0162	3.48	2.98
2:00	.022	3.62	3.12
2:30	.0280	3.65	3.15

Run 9
Normal Load 15 lb
Normal Stress 3.06 lb/in^2

Elapsed Time (min)	Displacement Dial Reading (in)	Shear Force (lb/in^2)	Shear Force Corrected (lb/in^2)
0:30	.0045	2.75	2.25
1:00	.0090	3.80	3.30
1:30	.0135	5.25	4.75
2:00	.0202	5.72	5.02
2:30	.0245	6.04	5.54

Run 10
Normal Load 15 lb
Normal Stress 3.06 lb/in^2

Elapsed Time (min)	Displacement Dial Reading (in)	Shear Force (lb/in^2)	Shear Force Corrected (lb/in^2)
0:30	.0044	1.22	0.72
1:00	.0096	1.85	1.35
1:30	.015	2.10	1.60
2:00	.0204	2.42	1.92
2:30	.0259	2.44	1.94

Run 11
Normal Load 5 lb
Normal Stress 1.02 lb/in^2

Elapsed Time (min)	Displacement Dial Reading (in)	Shear Force (lb/in^2)	Shear Force Corrected (lb/in^2)
0:30	.0049	1.20	0.70
1:00	.0094	1.75	1.25
1:30	.0145	2.00	1.50
2:00	.0202	2.45	1.95
2:30	.0260	2.50	2.00

Run 12
Normal Load 5 lb
Normal Stress 1.02 lb/in^2

Elapsed Time (min)	Displacement Dial Reading (in)	Shear Force (lb/in^2)	Shear Force Corrected (lb/in^2)	Elapsed Time (min)	Displacement Dial Reading (in)	Shear Force (lb/in^2)	Shear Force Corrected (lb/in^2)
0:30	.0052	1.10	0.60	0:30	.0038	1.20	0.70
1:00	.0099	1.65	1.15	1:00	.0092	1.74	1.24
1:30	.0155	2.30	1.80	1:30	.0140	2.01	1.51
2:00	.0208	2.51	2.01	2:00	.0202	2.45	1.95
2:30	.0260	2.51	2.01	2:30	.0255	2.49	1.99

Run 13
Normal Load 5 lbs
Normal Stress 1.02 lb/in^2

Run 14
Normal Load 5 lbs
Normal Stress 1.o2 lb/in^2

Elapsed Time (min)	Displacement Dial Reading (in)	Shear Force (lb/in^2)	Shear Force Corrected (lb/in^2)
0:30	.005	1.25	0.75
1:00	.0095	1.84	1.34
1:30	.014	2.10	1.60
2:00	.0204	2.45	1.95
2:30	.0246	2.46	1.96

Run 15
Normal Load 5 lbs
Normal Stress 1.02 lb/in^2

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13. ABSTRACT

Traditionally, the methods used to determine the mechanical properties of marine sediments were those used in the field of soil mechanics. These methods are generally acceptable when the sediment tested is plastic or at water contents below the liquid limit. However, for predicting in-situ conditions, that is for sediment at water contents above the liquid limit, the problem is complex.

Specifically, the determination of shear strength of an unconsolidated-undrained sample by the direct shear method was found to exhibit an angle of internal friction ranging from 19 degrees to 23.5 degrees. This indicates that the shear strength of the sediments is dependent on the normal load applied to it.

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Direct Shear						
Marine Sediment						
Normal Load						

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